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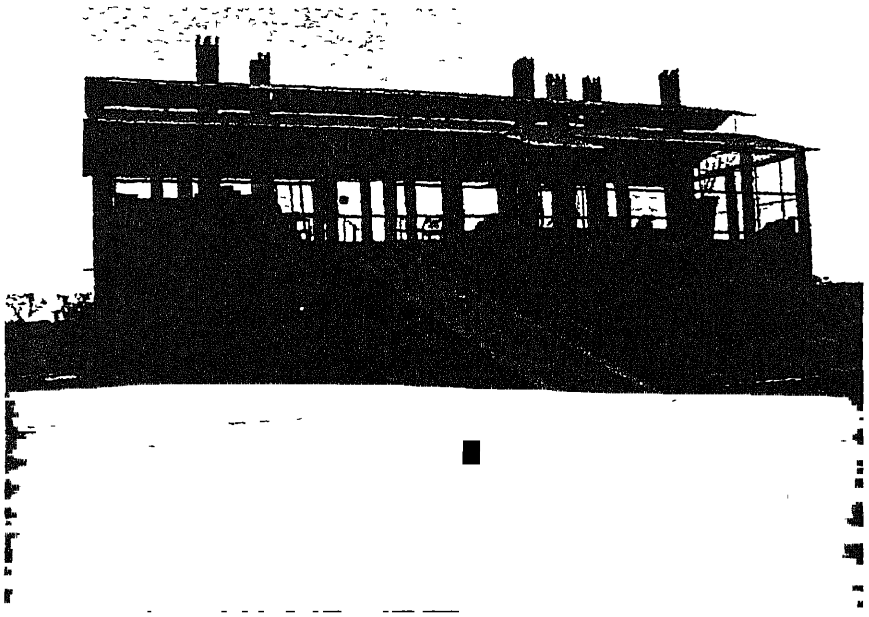
Development of emission standards and stack height regulation for the vertical shaft brick kilns (VSBK) vis-à-vis pollution control measures

Prepared for **Central Pollution Control Board, New Delhi**



TERI Project Report No. 2000EE68

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Executive summary

Bull's trench kilns (BTKs) with moving and fixed chimneys and clamps are generally used for firing bricks in India Emission standards for BTKs were introduced by the Central Pollution Control Board (CPCB) during 1996. The standards also recommend phasing out of moving chimney BTKs This has led to adoption of improved brick kiln technologies Under one such initiative, the Swiss Agency for Development and Cooperation (SDC) has introduced the Vertical Shaft Brick Kiln (VSBK) technology in India. At present there are about 20 VSBKs operating in different states e.g Madhya Pradesh, Maharashtra, Uttar Pradesh and Orissa. The main advantages claimed for VSBK are:

- Highest energy efficiency among all types of kilns
- Lower emissions
- Small area requirement
- Uniformity in the quality of the fired bricks

The technology is now well established in some parts of the country and emerged as a viable option for firing bricks. The existing emission standards on brick kilns pertains only to BTKs and were made before VSBK emerged as a potential technology for firing bricks in India The present study was undertaken for formulation of emission standards for VSBK technology.

The methodology followed included the following·

(1) Detailed literature review on VSBK technology
(2) Selection of VSBKs for monitoring environmental and energy performance with the consent from CPCB
(3) Detailed monitoring of selected kilns which included stack emissions, ambient air quality, work place environment and energy
(4) Prediction of dispersion of stack emissions and their impact on ground level concentrations using air pollution dispersion model, and
(5) Formulation of emission standards for VSBK

The emissions of suspended particulate matter (SPM) from the stack varied between 57 to 272 mg/Nm^3 The SO_2 emissions range between 13 to 118 mg/Nm^3. Differences in operating practices influence the emissions. Results of the ambient air quality show that the ground level concentrations (GLC) of SPM and SO_2 emissions were well below the prescribed limits of Indian standards for industrial area. Dust level in the working area varies between 312–3010 µg/m^3. The level of pollutants in working areas is related to the production level and ventilation. The specific energy consumption of VSBKs monitored varies between 0.74 to 1.26 MJ/kg fired brick.

Results of the air quality modelling shows that the incremental increase in the ground level SPM concentration is less than 11 µg/m^3 confining to a distance of 100 metre from the kiln in the downwind direction. A detailed analysis was carried out to evaluate the performance of VSBKs and a vis-à-vis comparison with existing technologies in brick making as well as other similar firing technologies especially in small scale industrial sector to recommend the emission standards. Based on the analysis the following recommendations are made for VSBK technology:

1. Maximum permissible limit of 250 mg/Nm^3 (normalised at 14% O_2) for SPM is proposed
2. Keeping in view the requirements of environmental regulatory authorities for monitoring stack emissions, one stack per shaft is suggested
3. It is recommended that the stack height of VSBK should not be less than 14 metre from the natural ground level.
4. Incorporation of pollution control system is not being recommended for VSBKs keeping in view the lower emission load of pollutants and technical difficulties in incorporating any pollution control system in the natural draught system operating at very low draught.

1

Introduction

1.1 Indian brick industry

India is the second largest producer of bricks after China. The estimated brick production during 2000-01 was close to 140 billion bricks. The Indian brick industry is unorganised with small production units clustered in rural and peri-urban areas. There are more than 100,000 brick kilns operating in the country. Brick making consumes about 24 million tonnes of coal and several million tonnes of biomass fuels per year. Coal consumption by the brick industry is approximately 8% of the total coal consumption in the country. The share of energy in total costs of brick production is 35 to 50%. Several types of brick kilns are used for firing bricks. The choice of technology depends generally on factors such as scale of production, soil and fuel availability, market conditions and skills available. *Table 1.1 shows brick kiln technologies used in the country*

Table 1.1 Brick kilns in India (2001)

Kiln type	*Typical production capacity range (lakh bricks per year)*#	*Approximate Number of kilns*
BTK-Fixed chimney	30 - 100	20000
BTK-Moving chimney	20 - 80	13000
High draft/zig-zag firing	30 - 50	200
Clamps	0 5 - 10	> 60000
Vertical shaft brick kiln (VSBK)	5 - 40	20*

# The brick making season in the country is generally 150–200 days in a year

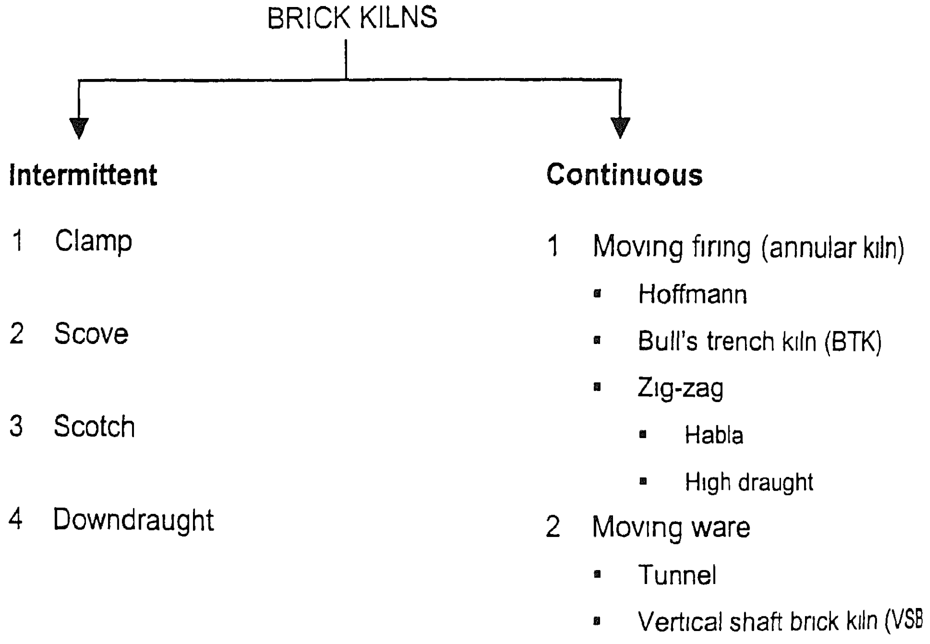
* October 2002

The brick-producing regions in India can be categorized into two major zones based on nature of soil availability.

- Indo-Gangetic Plains, consisting of the north and north east part of India. Good quality alluvial soil is available for brick making in this region and large capacity BTKs are found in this region. This region caters to about 65% of the total production.
- Peninsular and coastal India, consisting of the west, central and southern parts of India accounts for the rest 35% of total production. This region

has shortage of good quality soil for brick making At present clamps and moving chimney BTKs are used for brick production VSBK technology has higher potential in this region.

The brick kilns in general can be classified into (1) intermittent kilns and (2) continuous kilns (figure 1.1). An Intermittent kiln without permanent kiln structure is commonly called as clamp. Clamps are generally used when the volume of production is small. The production capacity of clamps generally ranges from 5,000 to 5,00,000 bricks per firing. A variety of fuels such as coal, firewood, various types of agricultural residues, dungcakes etc. are used in clamps. The arrangement of bricks in a clamp generally depends on the type of fuel used. Intermittent kilns have low energy efficiencies as most of the heat in the flue gases, fired bricks and kiln structure remains unutilized.



BRICK KILNS

Intermittent

1 Clamp
2 Scove
3 Scotch
4 Downdraught

Continuous

1 Moving firing (annular kiln)
   - Hoffmann
   - Bull's trench kiln (BTK)
   - Zig-zag
      - Habla
      - High draught
2 Moving ware
   - Tunnel
   - Vertical shaft brick kiln (VSB

Figure 1 1 Classification of brick kilns

Continuous kilns incorporates heat recovery features to utilise heat in fired bricks as well as heat available in hot flue gases. These kilns are superior to intermittent kilns in terms of energy efficiency as well as the quality of bricks. Continuous kilns include bull's trench kilns (BTKs) with moving chimney and fixed chimney, Hoffmann kiln, high draught kilns and vertical shaft brick kiln (VSBK).

Brick kilns can also be classified according to the production capacity. The Gazette Notification on "emission standards" for brick kilns classifies brick kilns into three categories:

(1) Small (production capacity less than 15000 bricks per day)
(2) Medium (15000 to 30000 bricks per day)
(3) Large (more than 30000 bricks per day)

2 Emission standards for brick kilns

A notification on emission standards for brick kilns was issued by the Ministry of Environment and Forests (MoEF), GOI, in April 1996. The notification presents standards for maximum allowable suspended particulate matter (SPM) concentration in flue gases (table 1.2) and minimum stack height for brick kilns (table 1.3). The notification also proposes a ban on the use of moving chimney BTK. The time limit for changing over to fixed chimney in place of moving chimney(ies) is 30th June 2002 In northern India, a large number of BTKs have either been converted to the fixed chimney type or are in the process of conversion. However, the process of conversion in Southern, Central and Western regions is quite slow probably due to the smaller size of the kilns and non-availability of suitable kiln designs and trained manpower for kiln construction.

Table 1.2 Emission standards for brick kilns

Size	*Kiln capacity*	*Maximum concentration limits of SPM (mg/Nm^3)*
Small	Less than 15,000 bricks per day (less than 15 ft trench width)	1000
Medium	15,000 to 30,000 bricks per day (15-22 ft trench width)	750
Large	More than 30,000 bricks per day (More than 22 ft trench width)	750

Note The above emission limits are achievable by installing fixed chimney/ high draft kilns and/ or settling chamber
Source· Ministry of Environment and Forests (MoEF), Government of India

The following stack heights are prescribed for optimal dispersion of particulate matter in brick kilns (table 1.3).

Table 1.3 Stack height regulations for brick kilns

Size	*Kiln capacity*	*Stack height*
Small	Less than 15,000 bricks per day (less than 15 ft trench width)	Minimum stack height 22 metre [OR] Induced draught fan operating with minimum draught 50 mm WG with 12 metre stack height
Medium	15,000 to 30,000 bricks per day (15 ft to 22 ft trench width)	Minimum stack height 27 metre with gravitational settling chamber [OR] Induced draft fan operating with minimum draft 50 mm WG with 15 metre stack height
Large	More than 30,000 bricks per day (More than 22 ft trench width)	Minimum stack height 30 metre with gravitational settling chamber [OR] Induced draft fan operating with minimum draft 50 mm WG with 17 metre stack height

Source Ministry of Environment and Forests, Government of India

1.3 Introduction to vertical shaft brick kiln (VSBK) technology

1.3.1 Historical development

Vertical Shaft Brick Kiln (VSBK) technology is an energy efficient technology for firing clay bricks. It is particularly suited to the needs of brick production in developing countries – which is small scale and decentralized type. The evolution and initial development of VSBK technology took place in rural China. The first version of VSBK in China originated from traditional updraft intermittent kiln during 1960's During 70's, the kiln became popular in several provinces of China. In 1985, Chinese government commissioned the Energy Research Institute of the Henan Academy of Sciences at Zhengzhou (Henan province), to study the kiln to improve the energy efficiency Several thousand VSBKs were reported to be operating in China in 1997 Attempts to disseminate VSBK technology outside China started in early 1990's. Apart from India, the VSBK technology was demonstrated in several Asian countries such as Nepal, Afganistan, Pakistan, Vietnam and Bangladesh.

1.3.2 VSBK technology in India

Under an 'Action Research Project' supported by the Swiss Agency for Development and Cooperation (SDC), four VSBK pilot plants were field-tested during the period 1996-99. The locations for the four pilot plants were selected so as to test VSBK technology under different 'soil-fuel-climate-market' conditions. The salient features of the VSBK demonstration units in India are shown in table 1.4

Table 1.4 Salient features of VSBK demonstration units in India

	VSBK-A	*VSBK-B*	*VSBK-C*	*VSBK-D*
Location features				
1 Place	Datia	Berhampur	Palghat	Pune
2 State/region	Madhya Pradesh (Central India)	Orissa (East India)	Kerala (South India)	Maharashtra (West India)
3 Soil type	Red & black soil	Laterite/red soil	Red soil	Black soil
4 Climatic region	Sub-tropical wet and dry	Tropical wet	Tropical wet	Tropical wet and dry
5 Prevalent local kiln	Clamp	Clamp & moving chimney BTK	Clamp	Clamp
6 Fuel combination	Cow dung, coal	Coal	Rubber firewood	Coal
VSBK				
1 Year and month of commissioning	May, 1996	May, 1997	April, 1998	January, 1999
2 Number of shafts	2	2	4	2
3 Shaft cross-section (m × m) Shaft-1 Shaft-2				
	1×1	1×1 75	1×1 75	1×2
4 Shaft height	1× 1 5	1×1 75	1×2	1 25×2
5 Chimney height from the ground level (metre)	4 95 m	4 05 m	4 95 m	4 50 m
	11 0	10 5	10.0	10 7
6 No of Chimneys/stack				
7 Material of construction of chimney				
	2	2	2	2
8. Production capacity (bricks/day)	Brick masonry	Brick masonry	Brick Masonry	Brick Masonry
	4500	6500	7500	8500
9 Fuel	Coal	Coal	Lignite briquette	Coal

Presently around 20 VSBKs are in operation in Madhya Pradesh, Maharashtra, Orissa and Uttar Pradesh. A list of places where VSBKs have been installed under the SDC sponsored India Brick Project (IBP) is given as table 1.5.

Table 1.5 Vertical shaft brick kilns (VSBKs) in India (October 2002)

S No	Location	*State*	*Number of kilns*
1	Datia	Madhya Pradesh	2
2	Gwalior	Madhya Pradesh	3
3	Tekanpur	Madhya Pradesh	1
4	Guna	Madhya Pradesh	1
5	Varanasi	Uttar Pradesh	1
6	Bareily	Uttar Pradesh	1
7	Palghat	Kerala	1
8	Kankia, Gram Vikas	Orissa	1
9	Asurmunda	Orissa	1
10	Mohuda	Orissa	1
11	Pune	Maharashtra	1
12	Nimbut	Maharashtra	1
13	Aurangabad	Maharashtra	1
14	Amravati	Maharashtra	1

Several design modifications have been incorporated under the IBP in the original Chinese VSBK design to improve its performance in energy, environment and product quality aspects These include:

- Increasing cross-sectional area of shaft to increase production capacity.
- Increasing the height of the shaft to improve energy efficiency.
- Increasing the height and the area of the chimney and use of a single chimney per shaft instead of two chimneys per shaft.
- Incorporation of shaft lids to reduce air pollution at the working platform.
- Use of cooling chambers for controlled cooling of the unloaded bricks.
- Instrumentation (thermocouples to measure brick and flue gas temperature) for kiln operation and control.

Further efforts are being made to reduce the cost of the kiln, simplify its operation and demonstration in new regions. Several new VSBKs are under planning and construction stage, which will soon become operational. The main advantages claimed for VSBK technology are:

a) Highest energy efficiency among all types of kilns.
b) Lower emissions.
c) Small area requirement.
d) Uniformity in the quality of the fired bricks.

1.4 Introduction to the Study

The existing emission standards on brick kilns pertains only to annular kilns (BTKs and high draft kilns) and were made before VSBK emerged as a potential technology for firing bricks in India. With this background it was felt that there is a need to formulate separate emission standards for VSBK technology.

TERI was entrusted by the Central Pollution Control Board (CPCB) to carry out a study on "Development of emission standards and stack height regulation for vertical shaft brick kilns vis-a-vis pollution control measures" The study involved detailed environmental and energy monitoring of four VSBKs with an objective to come out with environmental norms for suspended particulate matter (SPM) emissions and chimney height for VSBK technology

1.5 Outline of the report

An introduction to the VSBK technology is given in chapter 2 covering the operation and design aspects The methodology for environmental performance including monitoring of stack emissions, work place and ambient air quality are described in chapter 3. The methodology for environmental modelling for the development of emission norms for SPM are also explained in this chapter

The results of detailed performance monitoring of the following VSBKs covering environmental and energy aspects are presented in chapter 4.

- VSBK–1: VSBK – Service Centre, Datia - Double chimney per shaft [monitored during May 2001]
- VSBK–2. VSBK – Gwalior [monitored during May 2001]
- VSBK–3: VSBK – Nimbut [monitored during December 2001]
- VSBK–4 VSBK – Service Centre, Datia - Single chimney per shaft [monitored during January 2002]

The air quality dispersion model results are described in detail in chapter 5. Approach to delineate standards for SPM and stack height are elaborated in chapter 6. The conclusions of the study are provided in chapter 7.

2 Vertical shaft brick kiln (VSBK) technology

2.1 Working principle

The VSBK is a vertical kiln with stationary fire and moving brick arrangement. Figure 2.1 shows the cross-section of a two-shaft VSBK kiln The kiln shaft has rectangular/ square cross section The kiln operates like a counter current heat exchanger, with heat transfer taking place between the air (moving upwards) and the bricks (moving downwards). The kiln can be divided into three distinct sections. The top section is the brick-preheating zone, the middle section is the firing & heat soaking zone and the lower section is the cooling zone for bricks. The shaft wall (inner surface of the kiln) is usually lined with refractory bricks and the outer kiln wall is made up of red brick. The gap between the shaft wall and outer kiln wall is filled with materials such as clay, fly ash etc. VSBK is a natural draft kiln, requiring no electricity for supply of combustion air. The air required for combustion enters from the bottom of the kiln It extracts the heat from the cooling bricks before reaching the firing zone. The flue gases leaving the firing zone exchange heat with dry bricks loaded thereby preheating them. The flue gases finally enter the chimney through the flue duct at a temperature of 60 to 150°C. Each shaft is

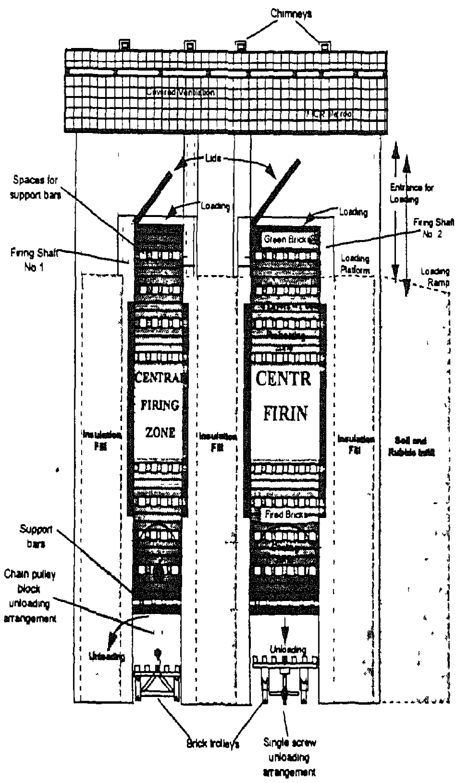


Figure 2.1 Schematic of VSBK

Figure 2.1 Cross-section of a two-shaft VSBK kiln

provided with two chimneys placed diagonally opposite to each other Lids are provided at the shaft top which direct the gases to pass through chimney. A single screw jack system is used for unloading of the fired bricks.

High unloading temperatures can lead to formation of cooling cracks[a] in the fired bricks. To reduce the formation of cooling cracks, cooling chambers are provided at the end of the unloading tunnel. The unloaded bricks can be kept in these chambers for controlled cooling of bricks. These chambers are particularly useful for high vitrification temperature soils (vitrification temperatures > 1000°C).

2.2 Operation

Dry bricks are loaded from kiln top in batches. Each batch has four layers of bricks in a predetermined pattern (figure 2.2) A predetermined quantity of crushed coal is also fed along with dry bricks. The number of bricks per batch depends on the cross-section of the shaft. Larger the area of cross-section, higher will be number of bricks produced in a batch. Table 2.1 shows the production capacity of bricks per shaft per day in VSBKs.

Table 2.1 Production capacity in VSBKs

Shaft size (metre X metre)	Production capacity (bricks per day)
1 X 1	2000
1 X 1.5	3000
1 X 1.75	3500
1 X 2	4000
1.25 X 2	5000

Note (1) For brick size of 230 mm X 110 mm X 70 mm, And
(2) Number of unloading assumed as 11 batches per day

Unloading of fired bricks is carried out at an interval of 2-3 hours. A trolley mounted on a screw jack is the main equipment used for unloading the bricks. The unloading of bricks creates space at the top of the shaft in which a new batch of bricks is loaded. The procedure of unloading and loading is now described in following paragraphs.

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[a] Cracks formed due to sudden cooling of fired bricks This problem has been observed is some VSBKs where the unloading temperature of bricks exceeds 200 °C

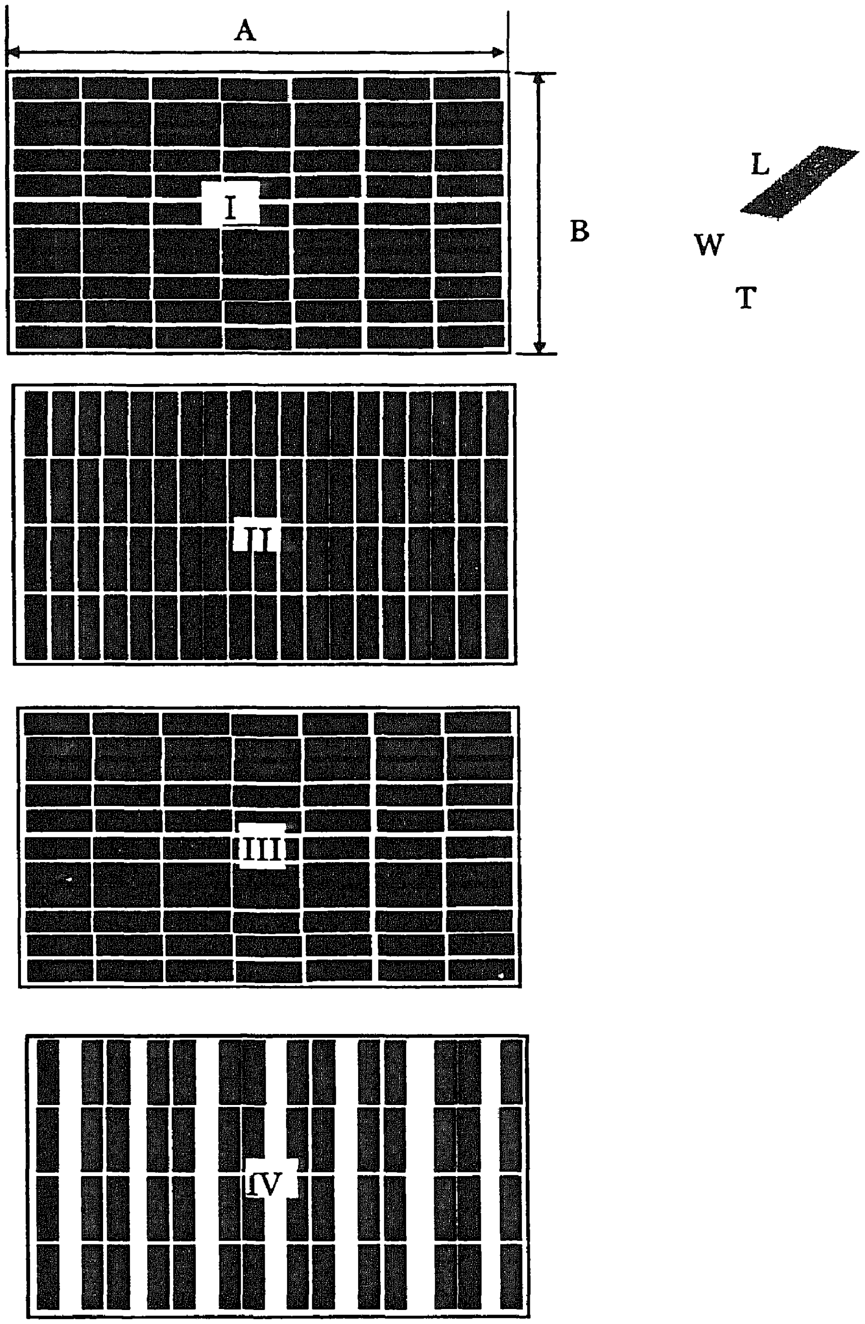


Figure 2.2 Layer by layer brick arrangement in a batch

The sequence of operations for unloading a batch is shown in figure 2.3. Figu 2.3 (a) shows the normal operating condition:

- The column of bricks in the shaft is resting on support bars (solid or hollow rectangular steel bars).
- Empty trolley is resting on the ground.

- The screw jack is in fully retracted position.

For unloading, the trolley is lifted up using the screw jack. On lifting, the wooden planks kept on the trolley, go in the gap between the support bars and touches the bottom surface of the brick setting. On further tightening of the screw, the weight of the brick column is transferred on to the trolley and the support bars become free and are pulled out. This position is shown in figure 2.3 (b), in which:

- The screw jack is in fully extended position.
- The support bars have been withdrawn and the brick column in the shaft is now resting on the trolley.

After removal of the support bars, the brick column resting on the trolley is lowered using the screw jack. The lowering is continued till the row of gaps in the brick setting are just above the top level of the support beam. This position is shown in figure 2.3 (c). Now the support bars are inserted in the gaps. After inserting the support bars, the lowering is continued till the support bars rests on the support beams and the weight of brick column is again transferred back on to the support bars. Further lowering of the trolley results in detachment of one batch of fired brick from the main brick column. The batch resting on the trolley is lowered to the ground this is shown in figure 2.3 (d), in which:

- The screw jack is in fully retracted position.
- The main brick column is now resting on the support bars and the trolley with a batch of fired bricks is resting on the ground.

The completion of unloading operation creates space for loading a new batch of green bricks at the top of the shaft. The bricks are arranged in the shaft in layers as per the arrangement shown earlier in figure 2.2. Three densely packed layers are followed by a fourth layer having gaps for support bars Crushed coal (particle size 0-15 mm) is weighed and spread over each layer of bricks.

The fuel added along with bricks is referred to as "external fuel". Crushed coal is used as external fuel in VSBKs Apart from the external fuel, generally some powdery fuel is also added in soil during soil-mix preparation stage, this fuel is referred to as "internal fuel". A number of fuels such as coal powder, fly ash, bagasse, rice husk etc are used as internal fuels. The extent to which internal fuels can be used is dictated by soil quality and desired brick quality

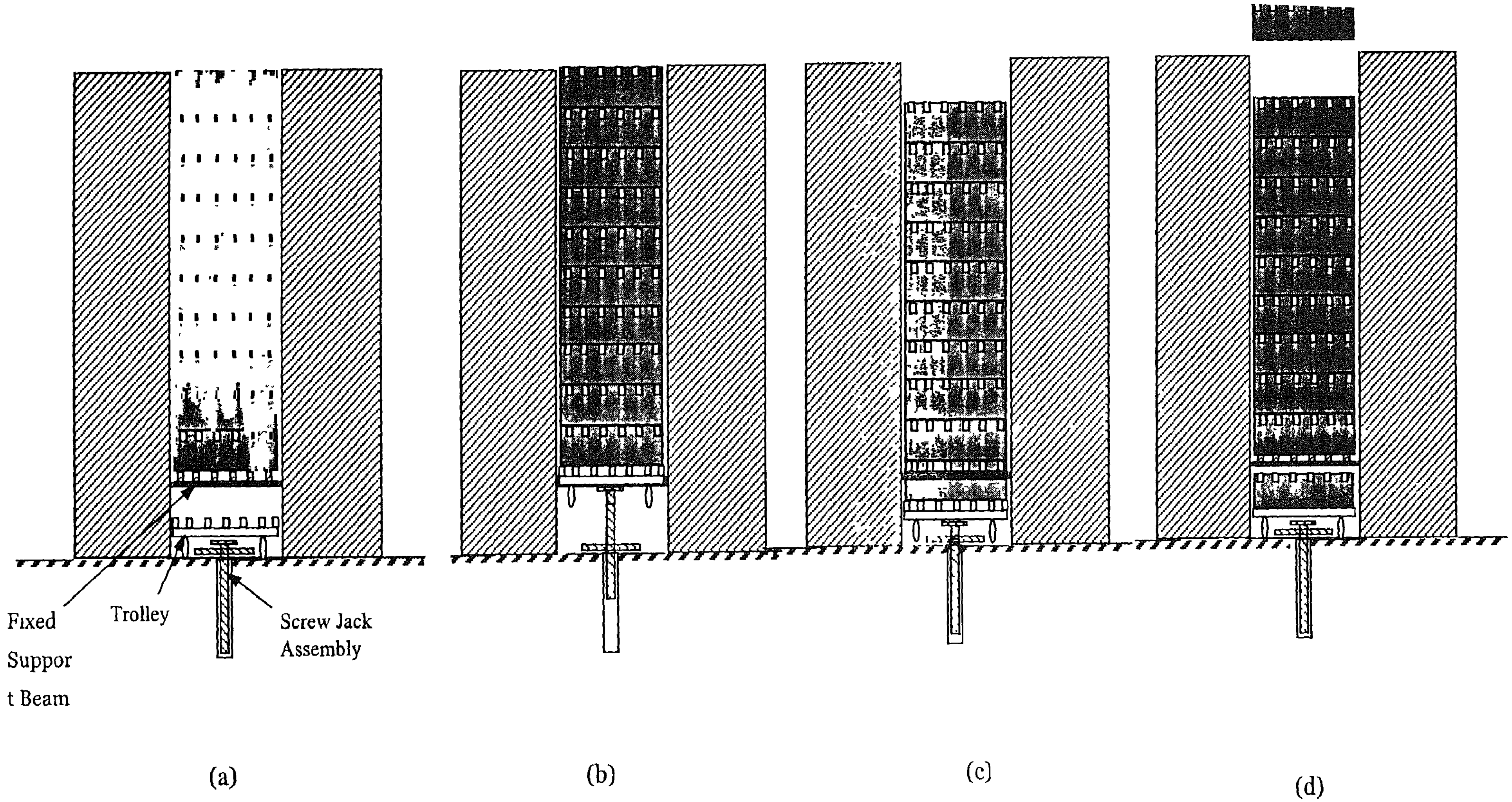


Figure 2.3 Operation Sequence of VSBK

2.3 Design

The most important component in VSBK design is the determination of the dimensions of the shaft (cross-section and height).

(i) Cross-section of the shaft

The nominal shaft cross-section is chosen based on the desired production capacity as per table 2.1. The exact shaft cross-section is calculated based on the size of dry green bricks. The internal shaft cross-section dimensions A and B (refer figure 2.2) are calculated using formulae as given below.

$A = (L + G) \times N_L$

$B = (L + G) \times N_w$

Where,

L = Length of dry green brick

G = Gap between bricks (of about 10 mm) required to ensure air/gas flow and for accommodating fuel between the bricks

N_L = Number of bricks accommodated along dimension A (e.g $N_L = 7$ for brick arrangement shown in figure 2.2)

N_w = Number of bricks accommodated along dimension (e.g. $N_w = 4$ for brick arrangement shown in figure 2.2)

(ii) Height of the shaft

The height of the shaft varies between 3.6 to 6.0 m (i.e. number of batches of bricks that can be accommodated in the shaft varies between 8 to 13). The height of the shaft depends on the strength of dry green bricks available for brick production The regions where good quality green bricks are available e.g. Indo-Gangetic plains, shaft height of 5.5-6.0 m is used. For areas having poor brick quality e.g. Maharashtra, shaft height of 4.0-5.0 m is used. The height of the shaft is calculated as below:

$H = [(W + 4) \times 4 \times N] + W + 50$

where

H = Height of shaft in mm

N = Number of batches in the shaft

W = Width of brick mm

The thickness of the walls of the kiln is determined depending on the storage and working area requirement at the kiln top. Figure 2 4 shows an example of major dimensions of the VSBK kiln.

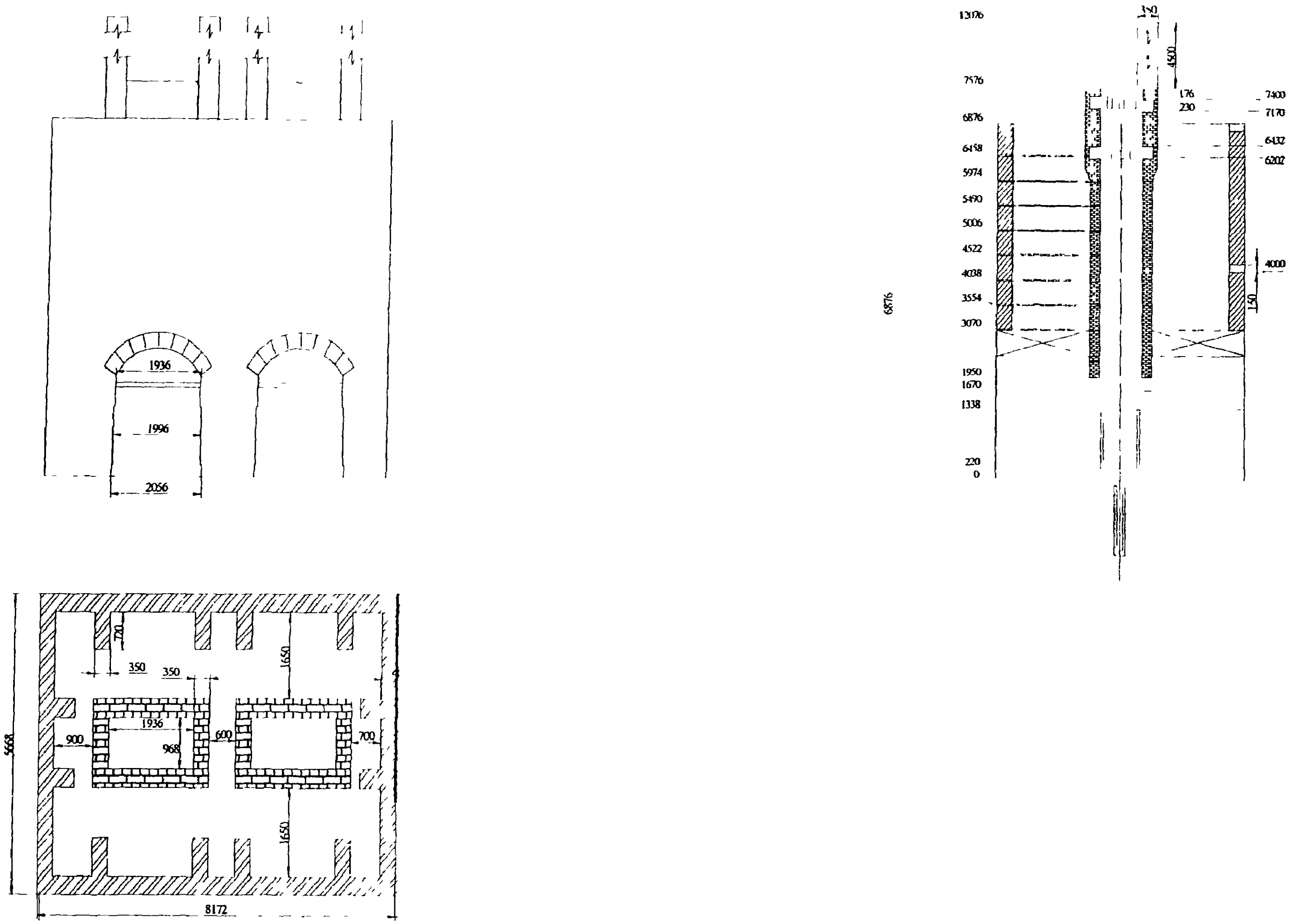


Figure 2.4 VSBK-Varanasi

2.4 Construction

The typical construction cost of single VSBK shaft ranges from Rs 2 5 to 3.5 lakh. The bill of quantity for a 2 shaft VSBK are provided in table 2.2. The construction period of a VSBK ranges from 30 to 45 days. VSBK construction requires supervision from a trained construction supervisor/ engineer. Special care is required during following stages of construction:

- Layout marking.
- Arch construction
- Shaft construction particularly for the refractory brick masonry work and ensuring verticality of the shaft.
- Flue gas outlet construction.

Table 2.2 Construction materials required for a two-shaft VSBK (8000 bricks day capacity)

S No	Item material	*Specification*	*Quantity*
1	Bricks	9'×4'×3'	40,000
2	Refractory bricks	9'×4'×3'	3,100
3	Refractory clay	50 kg/bag	10 bags
4	Cement	50 kg/bag	70 bags
5	River sand	400 cu ft/truck	4 truck
6	Boulder (Big stone)	400 cu ft/truck	4 truck
7	I section for screw support	150×80, L=2520 mm	4 Nos
8	I section for Rail beam for support bar	200×100, L=2480 mm	4 Nos
9	Channel beam for shaft support	L=2420 m, 125×55 mm^2	8 Nos
10	Support plate for screw I beam	350 mm×250 mm×8 mm	4 Nos
11	Support plate for brick support I beam	250 mm×250 mm×8 mm	8 Nos
12	Support plate for channel steel	280 mm×250 mm×8 mm	8 Nos
13	Trolley guide	50 mm×100 mm, L=1100 mm	8 Nos
14	Angle iron for trolley track	50 mm×50 mm×5 mm=6000 mm	4 Nos
15	Steel iron rod	Dia 6 mm	90 kg
16	Screw jack assembly		2 no
17	Trolley		2 no
18	Roofing material	According to local requirement	

Note The above table does not include the requirements for ramp/lifting arrangements, cooling chambers

3

Methodology for the study

The various steps in the methodology followed in the project were:

- Project inception and planning
- Literature survey
- Field studies, data analysis and modelling
    - Source characterization and ambient air monitoring
    - Work environment monitoring
    - Ambient air monitoring
    - Feasibility analysis of suitable control technologies for cost effective performance
    - Arriving at standards for stack height and fugitive emissions
    - Energy related performance of VSBKs (energy audit)

3.1 Kiln selection

At the time of initiating the study, a total of 12 VSBKs were operating located in the states Madhya Pradesh (5), Maharashtra (4), Orissa (1) and Uttar Pradesh (2). The basic criteria in the selection of kilns included the following factors:

- Production capacity
- Number of shafts in the kiln
- Type of chimney
- Geographical location

3.1.1 Production capacity

The present production capacity of brick making units uses VSBK range from 3000 bricks per day to 20,000 bricks per day. Both the smallest capacity (VSBK–Nimbut) and the largest capacity (Yade Bricks, Gwalior) were selected for the study. While VSBK–Nimbut is a single shaft VSBK, Yade Bricks–Gwalior has four shafts.

3.1.2 Kiln management (ownership profile)

Kiln management has important bearing on the operating practices and hence the performance of the kiln.

Out of three kilns selected for the study, one of the kilns (VSBK-Service Centre, Datia) was owned by an institution – Development Alternatives, a partner organisation in the India brick Project. The kiln was selected because of its experience staff. And hence the kiln represents the case of best operating practices. The other two kilns are operated by private entrepreneurs representing commercial kilns in the field.

3.1.3 *Type of chimney*

In the traditional design, VSBK has masonry chimney. During discussions with CPCB officials the need for a single chimney arrangement to simplify the monitoring was expressed. Keeping this need in view. A single chimney was erected at the VSBK–Service Centre, Datia and monitored for its performance under the project.

3.1.4 *Geographical location*

Majority of the existing VSBKs are located in the states of Madhya Pradesh (5 number) and Maharashtra (4 number). These two states also show a large potential for VSBK technology Therefore, the kilns located in these two states were selected for monitoring.

With these considerations, following kilns were selected for carrying out the performance monitoring. The kiln selected for monitoring is referred as under:

- VSBK Service Centre–Datia [to be referred as **VSBK–1**]
- Yade Bricks–Gwalior [to be referred as **VSBK–2**]
- VSBK–Nimbut [to be referred as **VSBK–3**]
- VSBK–Datia (single chimney system) [to be referred as **VSBK-4**]

The seasonal effects were also studied; two kilns were monitored during winter and two kilns during summer with Datia kiln being monitored both during summer and winter.

3.2 Sources of pollution and methodology for Environment monitoring

In the brick production, the main type of pollution is air pollution. Sources of air pollution in VSBKs are stack emissions and fugitive emissions from unloading and material handling. In order to study the environmental performance of the VSBK technology, detailed environmental monitoring of 4 VSBKs was carried out. The environmental monitoring includes stack emission monitoring, ambient monitoring and fugitive dust measurement in the work place. All the monitoring were carried out in the presence of CPCB officials.

3.2.1 Stack emissions

Stack gas emissions were monitored for particulate matter, SO_2 and NO_x. Stack emission monitoring was carried out as per the standard procedure recommended by the CPCB. Stack sampler (APM 615 of Envirotech make) was used to sample the flue gas for particulate and gaseous pollutant. For stack sampling a porthole was provided in each chimney at the height of 3 meters from the shaft opening. Flue gas temperature was measured by thermocouples and velocity was measured using differential density velocity monitor. Iso-kinetic sampling was followed for particulate sampling. Samples were collected for a period of 50 minutes to 60 minutes. Pre conditioned and weighed thimbles (GFA, whatman make) were used for sampling. Flow rate for gas analysis was maintained at 2 lpm (litre per minute) and the analysis was done by chemical method. Carbon monoxide (CO) levels were also checked using flue gas analyzer and Orsat apparatus. Fluegas samples from the last two monitoring (VSBK–Nimbut and single chimney–Service Centre) were also analyzed for Total hydrocarbons by the gas chromatographic method (GC). Figure 3.1 shows the stack monitoring being carried out.

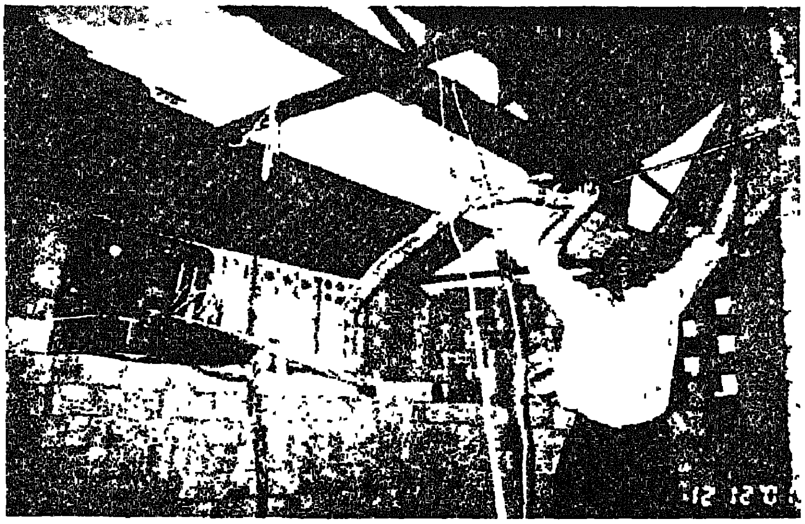


Figure 3.1 Stack emission monitoring at VSBK

During the monitoring (May 2001) two out of three shafts in VSBK–1 were in operation operation. VSBK–2 has four shafts and all of them were in operation during the monitoring. VSBK–3 is a single shaft kiln. Last monitoring was carried out in the single chimney at VSBK–4. The single chimney was erected by connecting the two vertical chimneys. Before erecting the single chimney system, the design was discussed with CPCB officials Some important details of the kilns monitored are summarised in table 3.1.

Table 3.1 Kiln details - stack emission monitoring

Location	Time of Monitoring	No of shafts	Shafts in operation	Shafts monitored	Chimney details	Height of porthole from loading platform (m)	Fuel addi (% in ener
VSBK-1	May 2001	3+1	2	2	Conventional 2 brick chimneys per shaft	2 5	Internal- External 60%
VSBK-2	May 2001	4	4	2	Conventional 2 brick chimneys per shaft	2 5	Internal- External- 60%
VSBK-3	December 2001	1	1	1	Conventional 2 brick chimneys per shaft	3 0	Internal External 55%
VSBK-4	January 2002	3+1	1	1	Metal single chimney	5.5	Internal External 55%

3.2.2 *Ambient air quality monitoring*

To study the impact of VSBK on near by environment, ambient air quality was monitored in 3 locations at each kiln. The ambient air monitoring locations were selected at a distance of 50 – 100 meters from the kiln. Suspended particulate matter (SPM), Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_2) were monitored in the ambient air High volume air sampler was used for sampling SPM at the flow rate of $1m^3$/min. Gaseous sampling kit attached to the high volume sampler was used for gaseous sampling and the flow rate was maintained at 1lit/min. The samplers were kept at a height of 3 to 10 meters from the ground level.

For SPM sampling, pre conditioned and weighed GFA filters were used For SO_2 and NO_2 the gas was bubbled through suitable absorbing media. SO_2 was analyzed by West and Gake method. For NOx measurement modified Jacob Hoischier method was followed Ambient air quality samplings were done for duration of 8hours Ambient meteorological conditions were also recorded Figure 3.2 shows the ambient air quality monitoring. The locations of field monitoring stations are shown in figure 3.3.

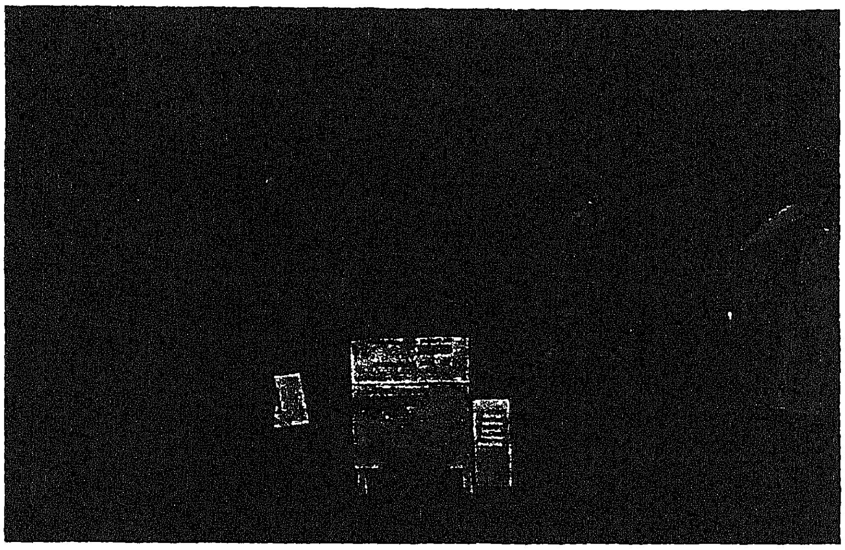
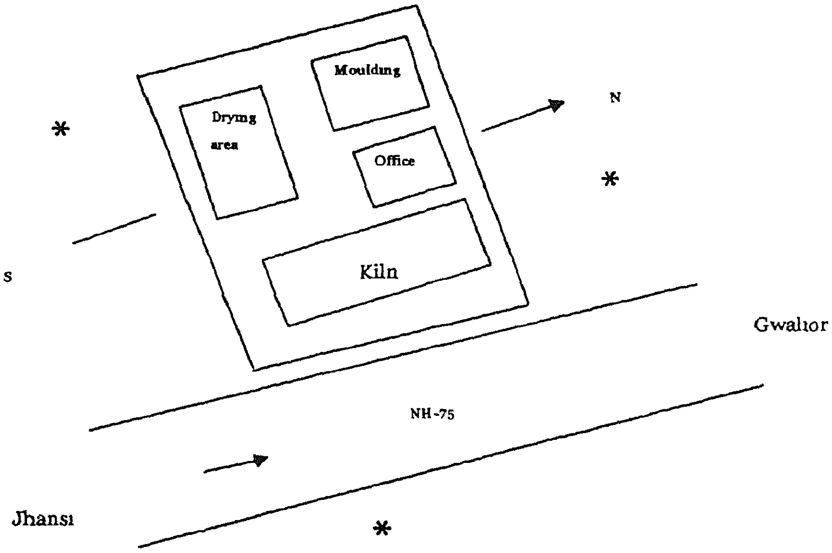


Figure 3.2 Ambient air quality monitoring



* indicates locations of ambient monitoring stations

Figure 3.3 Locations of field monitoring stations

3.2.3 *Work environment monitoring*

Concentration of dust or particulate (SPM) and carbonmonoxide (CO) in the work environment such as loading and unloading platform were monitored. Particles were collected on a pre conditioned and pre weighed membrane filters (Millipore, Ireland make) and analyzed by gravimetric technique. Personal dust sampler (SKC, USA make). Was used for sampling the air. The flow of the personal air sampler was calibrated by the soap bubble technique. During the monitoring the flow was maintained at 2 lit/min. The monitoring was done for a period of 8 hours. Figure 3.4 shows the personal monitoring of dust in the unloading area. CO levels in the working area were recorded by the personal CO monitors (National Dragger, USA make).

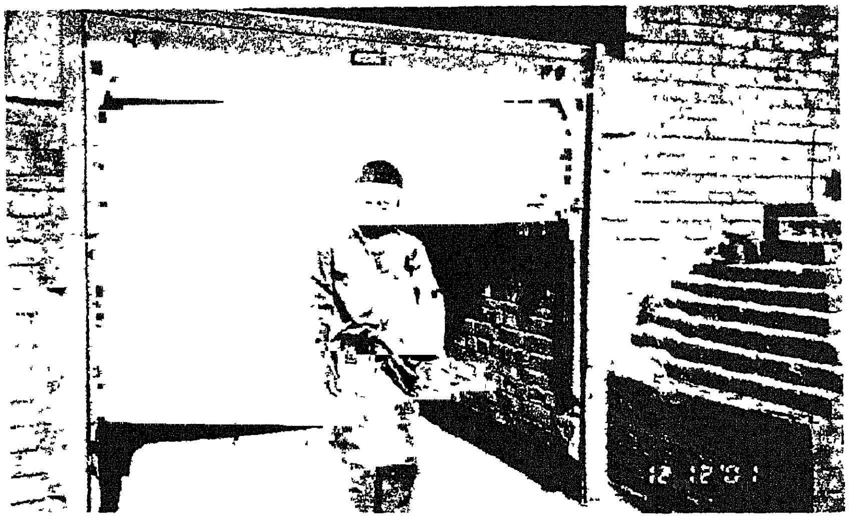


Figure 3.4 Personal monitoring for particulate in the unloading area

3.3 Energy monitoring

The energy audit of the above three kilns were carried out in order to study the energy use and various losses occurring in the system and arrive at suggestions for improving the performance. The study included the following aspects:

- Identification and quanitification of energy losses in VSBKs
- Study of the temperature distribution in the kiln for a clear understanding of the combustion and heat transfer occurring in the kiln
- Study of operating practices, mainly brick stacking arrangements, fuel used, fuel preparation & feeding practices and their impact on fuel consumption in the kiln

3.3.1 *Components involved in energy audit*

Different heat losses measured during the energy audit study are:

- Dry flue gas loss
- Radiation and convection losses from kiln outer surface
- Heat required for removal of mechanically held moisture in green dry bricks
- Heat required for irreversible chemical reactions
- Radiation loss from hot exposed bricks at the kiln bottom
- Residual heat in the unloaded fired bricks
- Heat contained unburnt gases
- Heat contained in unburnt fuel

For measuring various heat losses and to arrive at the specific energy consumption of the kiln, following measurements were taken·

- Flue gas composition (O_2, CO_2 and CO)
- Flue gas temperature
- Kiln surface temperatures
- Exposed bricks temperatures
- Temperature of fired bricks coming out of kiln
- Moisture content in dry green bricks at the time of loading in the kiln
- Ambient conditions – dry bulb temperature, wet bulb temperature, relative humidity
- Kiln production details
- Fuel consumption – internal and external

Apart from these measurements, samples of the following were also collected to carry out the analysis:

- Fuel – ultimate analysis, proximate analysis and gross calorific value
- Soil (used for brick making) – chemical analysis
- Ash – carbon content

3.4 Air quality model

The impact of emissions from the stacks on the ground level concentrations was estimated by using an air dispersion model named, as PTMTP. The PTMTP model is based on Gaussian Plume Equation. This is primarily a screening model applicable for POINT source emission. The impact of more than 1 stack emission (up to 25 sources/ stacks) on the ground level concentration can be screened at a time with the help of this model. The following source characteristics were used in the model.

- Emission load (g/s)
- Physical Stack Height (m)
- Stack gas Velocity (m/s)
- Stack Diameter (m)
- Flow Rate – optional,(m^3/s)
- Stack Gas Temperature (K)
- X & Y Coordinates

The model was run for various meteorological scenarios. For each run mean value of various meteorological parameters such as ambient temperature, Wind Speed, Wind Direction, Pasquill's Stability Classes, mixing Height and atmospheric pressure were considered to predict the impact on ground level concentration.

4

Results and analysis of kiln monitoring

VSBK–1, VSBK–2, VSBK–3 and VSBK–4 were monitored for the following performance:

- Stack emissions
- Ambient air quality
- Work station air quality
- Energy performance

The details of the results and the analysis are presented in the following sections. Details of the kilns, important kiln operating parameters and the energy balance of the kiln are given in Annex 4.1.

1 Stack monitoring results

In all kilns the stack samples were collected for a period of 50 to 60 minutes. Kiln operations were not altered and normal practices were followed in all kilns. It was observed that typically the kiln operators don't use lid during normal practices. This is exceptional in VSBK 1 and VSBK4, where the lid was used with proper sealing. The coal quality, size of the coal and quantity of internal and external fuel also varies from kiln to kiln. Other parameters such as location of fire zone during the monitoring, production capacity and duration of operation also influence the stack emission performance. The results of the stack emission monitoring are summarized in table 4.1. The details of the stack emission monitoring are given in the Annex. 4.2.

Table 4.1 Mean concentration of pollutants in the stack emissions

Parameter	*VSBK -1*	*VSBK –2*	*VSBK -3*	*VSBK-4*
Flue gas				
Temp (° C)	80	180	124	80
	(75 - 90)	(168 - 190)	(118 - 134)	(78 - 82)
Velocity (m/s)	2 1	2 9	1.3	1.2
	(2 0 - 2 2)	(2 8 - 3 0)	(1 2 - 1 5)	(1 15 -1.4)
Exhaust flow rate	599	838	391	207
(m^3/h)	(570 - 627)	(798 - 855)	(348 - 434)	(204 - 209)

Emissions				
Particulate	136	250	77	212
(mg/Nm^3)	(93 - 176)	(232 - 272)	(57 - 84)	(170 - 234)
SO_2 (mg/Nm^3)	17	36	62	53
	(13 - 25)	(27 - 44)	(39 - 118)	(48 - 62)
NO_X (mg/Nm^3)	42	79	68	74
	(36 - 50)	(57-91)	(55 - 81)	(70 - 78)
Hydrocarbons	NA	NA	507	634
(mg/Nm^3)			(480 - 624)	(580 - 712)
CO (ppm)	525 - 1160	1810 - 2310	780 - 1020	1846 -1994
CO_2 (%)	NA	NA	2.4 - 4.0	5.2 - 6.3

Figures in brackets indicate the ranges, NA – Not available

The stack monitoring result reveals that SPM levels in the flue gas vary from 57 mg/m^3 to 272 mg/m^3. The SPM levels in the flue gas are below the emission standards (750 mg/m^3) stipulated for BTKs. The SO_2 level vary from 13 to 118 mg/m^3. Whereas the NO_2 concentration vary from 36 mg/m^3 to 91 mg/m^3. The stack emissions are generally influenced by various parameters such as fuel quality, quantity of external fuel used, operational practice etc Among the 4 VSBKs monitored the SPM levels were high in the VSBK–2. Temperature of the flue gas was also observed to be higher than other kilns which is attributed to the operational practice. It was observed that in the VSBK–2 the operation was fast and the fire was in the upper zone. When the fire moves up the emission level also increases.

4.2 Ambient air monitoring

In addition to the emissions from kiln other parameters such as meteorological condition, topography and other activities in the near by vicinity affect the ambient air quality. The VSBK–1(&4) and VSBK–2 are located near high way. Stone crushers are located in the vicinity of VSBK 2. VSBK–1 and VSBK–2 were monitored during the summer season and the ambient temperature was above 40° C. At VSBK–1, during the monitoring in the summer season the wind velocity was less than 2 m/s during morning hours and in the evening the wind velocity was very high and at VSBK–2 the wind velocity was very high especially in the evening and night hours. Though this allows dilution of the pollutants from the stack emission, it also carries lot of dust from the nearby places. As the VSBK–2 is situated near the stone crushers the dust emitted by the crushers were also influence the ambient condition.

The VSBK–3 is located in the rural area and away from the highway. After single chimney erection the VSBK–4 was monitored in the winter season. During the winter monitoring the meteorological conditions were different from the previous monitoring in the same location. Most of the time calm conditions were observed and the temperature was below 20°C The summary of the ambient monitoring results is shown in the table 4.2. The detailed results are given in the Annex 4.3.

Table 4.2 Ambient air quality near the VSBK

Parameter	VSBK-1	VSBK-2	VSBK-3	VSBK-4	Ambient air quality standards*
SPM (μg/m^3)	192 - 346	189 - 352	95 - 147	70 - 129	500
RSPM (μg/m^3)	72 - 112	84 - 132	70 - 100	53 - 90	150
SO_2 (μg/m^3)	10 - 20	10 - 21	6 - 15	8 - 13	150
NO_2 (μg/m^3)	18 - 32	25 - 32	12-32	13 - 40	120

Note * = 24 hour standard for Industrial area

Following inferences are drawn from the ambient air quality results.

- Concentrations of all gaseous and particulate matter were below the prescribed Indian standards for Industrial area.
- Particulate levels were comparatively higher in the summer season. This may be due to the influence of high surface wind, which carries the re suspension dust and particulate from the vicinity.

4.3 Work area monitoring

The dust emissions and carbon monoxide levels at various working environment is shown in table 4.3.

Table 4.3 Average dust emission at various working environment

Location	*Carbon monoxide # (ppm)*	*Dust level (μg/m^3)*
VSBK-1		
▪ Unloading platform	4 - 7	720 -942
▪ Near loading area	16 - 24	1689 -2100
▪ Moulding section	BDL	392 - 523
VSBK-2		
▪ Unloading platform	12- 16	2720 -3010
▪ Loading area	140 - 184	2068 - 2314

VSBK-3		
▪ Unloading platform	3 - 7	420 - 500
▪ Loading platform	108 -116	930 -982
VSBK-4		
▪ Unloading platform	6 -12	312 - 428
▪ Loading Platform	20 - 35	920 -1050
Permissible limit of exposure (15 minutes)	400	

Carbon monoxide levels were monitored for a period of 15 minutes
BDL – Below detectable limits

The dust and CO levels in the working environment were highest at the VSBK-2 and lowest at VSBK–1 and VSBK–4. The higher levels of pollutants in the working areas may be attributed to the higher level of production, congested working space and poor ventilation at the loading platform at VSBK–2. The shaft lids were in use only at VSBK–1 (&4). This along with better ventilation and sufficient space for movement and storage of bricks is responsible for lower pollutant levels at the VSBK 1 (&4).

4.4 Mass emission load estimation

While we measured the concentration of pollutants from the stack emission, for better comparison the emission rate and mass emission load (kg pollutant/1000 bricks) were estimated from the concentration, velocity of the flue gases, stack dimensions and brick production rate. Emission rates were calculated as follows:

$$\text{Emission rate of pollutant (kg/hr)} = \frac{S \times Q_S}{10^6}$$

Where,

Q_s = Flue gas flow rate (25° C, 760 Hg mm), Nm^3/hr
Flow rate of flue gas Q_s = Velocity × Area of stack
S = Concentration of pollutant (mg/Nm^3)

From the emission rate, mass emission load for 1000 bricks is calculated as follows:

Mass emission load (kg/1000 bricks) = Pollutant emission rate (kg/h) x duration of production for 1000 bricks x no of chimney in each shaft

The calculated emission rate and mass emission load are shown in table 4.4.

Table 4.4 Emission loading estimation for the VSBKs

Parameter	*VSBK-1*	*VSBK-2*	*VSBK-3*	*VSBK-4*
SPM emission rate (kg/h)	0.08	0.22	0.03	0.04
SO_2 emission rate (kg/h)	0.01	0.03	0.02	0.01
NO_x emission rate (kg/h)	0.02	0.06	0.03	0.02
SPM emission in kg/1000 bricks	1.35	2.80	0.37	0.31
SO_2 emission in kg/1000 bricks	0.17	0.39	0.29	0.08
NOx emission in kg/1000 bricks	0.41	0.85	0.33	0.11
SPM emission/ kg fired brick (g/kg)	0.48	1.05	0.14	0.11
SO_2 emission/kg fired brick (g/kg)	0.06	0.14	0.112	0.026
NOx emission / kg fired brick (g/kg)	0.15	0.32	0.13	0.04

4.5 Energy performance

The energy performance of brick kilns is calculated as the thermal energy consumed per kg of bricks fired (MJ/kg brick fired). Coal is used as the external fuel in VSBKs and fuels such as coal powder, boiler ash, biomass fuels such as rice husk are added as internal fuel. While internal fuels are added during moulding process, the external fuel i.e. coal is added during each loading operation. The specific energy consumption of the kilns monitored are shown in table 4.5. Higher energy consumption observed in VSBK-2 was due to the unstable condition of the kiln and the higher fuel input leading to melting of bricks during the period of monitoring. The average specific energy consumption of the other three monitoring works out to be 0.81 MJ/kg fired brick. Detailed energy performance of the VSBKs are given in Annex 4.1.

Table 4.5 Specific energy consumption of VSBKs

Parameter	*VSBK-1*	*VSBK-2*	*VSBK-3*	*VSBK-4*
Coal use (kg/1000 brick)	58	61.6	65	87.5
Internal fuel (kg/1000 brick)*	200	200	65 (coal powder) 241 (fly ash)	70
GCV - coal (kcal/kg)	5460	5040	4770	5100
GCV - internal fuel (kcal/kg)	990	990	4270 (coal powder) 530 (fly ash)	5100
Weight of fired brick (kg)	2.8	2.7	2.4	3.1
SEC (MJ/kg)	0.74±0.04	0.79 ±0.04	1.26±0.04	1.07±0.04

GCV – Gross calorific value; SEC – Specific energy consumption

* Datia (double chimney) – coal ash, Gwalior – Coal ash;
Nimbut – coal powder & fly ash;
Datia (single chimney) – coal powder

The mass balance of a typical VSBK is shown in figure 4.1.

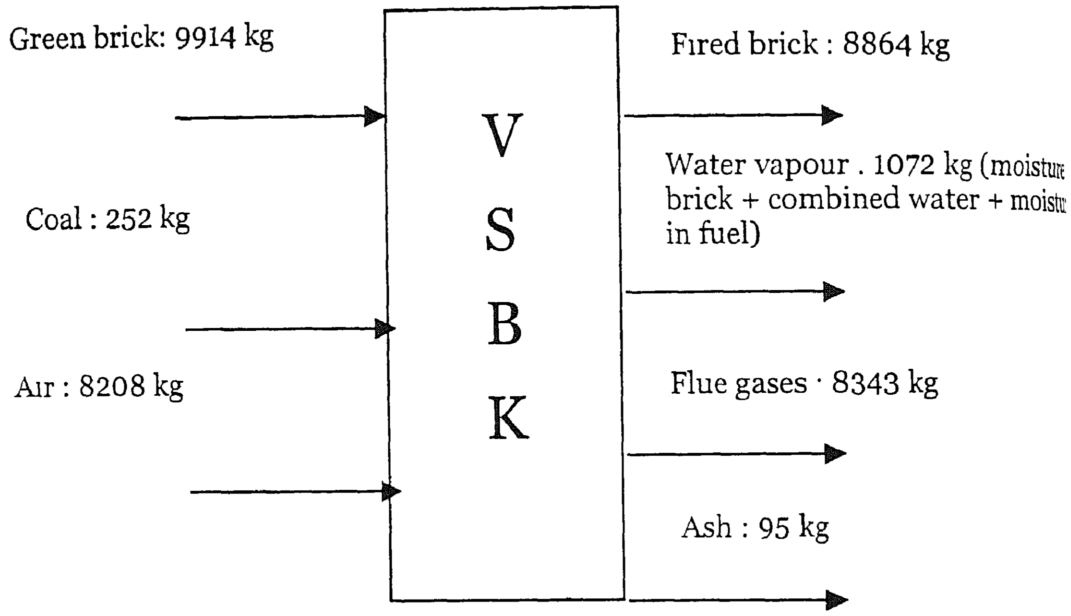


Figure 4.1 Mass balance in VSBK

5 Modeling results

5.1 Air quality dispersion model results

The dispersion of stack gases laden with pollutants and their impact on the ground level concentration has been studied by using mathematical models based on Guassian Plume. Computations have been made using the Screen and PTMTP models to estimate the SPM concentrations at various locations along the axis of the plume.

PTMTP is an Air Dispersion Model based on Gaussian Equation. This is primarily a screening model applicable for POINT source emission and requires following source characteristics.

1. Emission load (g/s)
2. Physical stack height (m)
3. Stack gas velocity (m/s)
4. Stack diameter (m)
5. Flow rate (m^3/s) – Optional
6. Stack gas temperature (K)
7. X & Y coordinates

The model can be used for processing 25 meteorological scenario per run. Ground level concentrations (GLC) using this model could be measured up to 30 receptors, which provided values for X, Y and Z coordinates from the source. The meteorological data required is average values of the following parameters:

1. Ambient temperature (K)
2. Wind speed (m/s)
3. Wind direction (degree)
4. Pasquill's stability classes (1–6 : Highly unstable – Highly stable)
5. Mixing height (m)
6. Atmospheric pressure (MB)

PTMTP model performs batch wise calculation of GLC for every meteorological scenario. For each kiln the model was run for various stability classes (table 5.1).

Table 5.1 Stability class for the PTMTP model

Stability class	*Condition*
A	Highly unstable
B	Moderately unstable
C	Slightly unstable
D	Neutral
E	Moderately stable
F	Highly stable

The output of PTMTP gives total GLC in g/m^3 or µg/m^3 due to all stacks or an individual stack at any desired receptor point under a specific set of meteorological scenario.

5.1.1 PTMTP model results for VSBK-1

Figures 5.1a to 5.1e show the modelling results for the VSBK–1 for different wind speeds- 1-5m/s. For the worst dispersion scenario i.e wind velocity of the order 1m/s, maximum GLC is about 1.0 µg/m^3 at a horizontal distance to 30m from the stack. The concentration tends to decrease with better dispersion on account of increased wind speeds and greater distance from the source.

Figure 5.1a PTMTP results for VSBK-1 for the average wind speed of 1 m/s

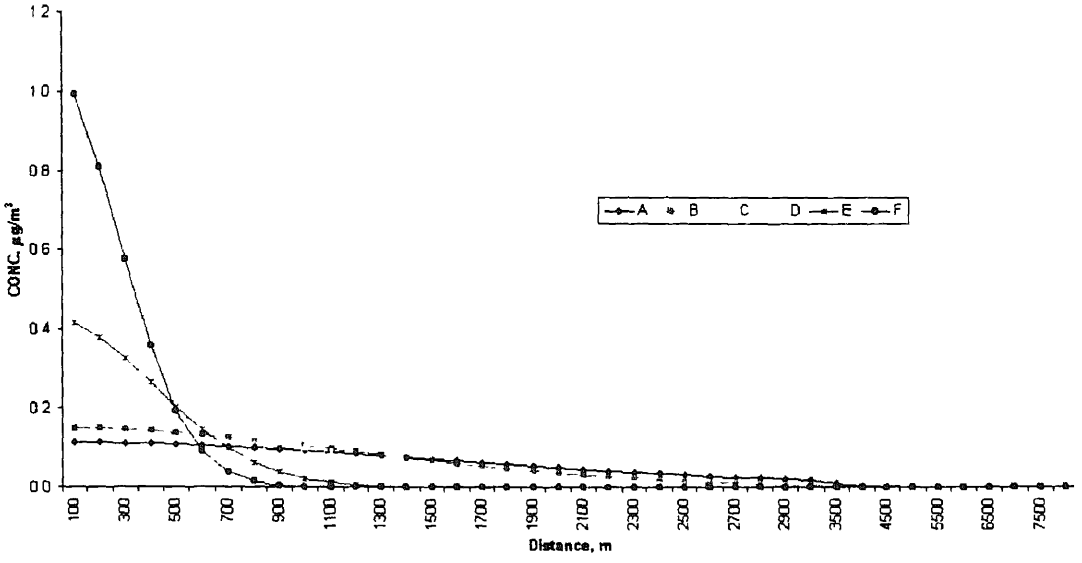


Figure 5.1b PTMTP results for VSBK-1 for the average wind speed of 2 m/s

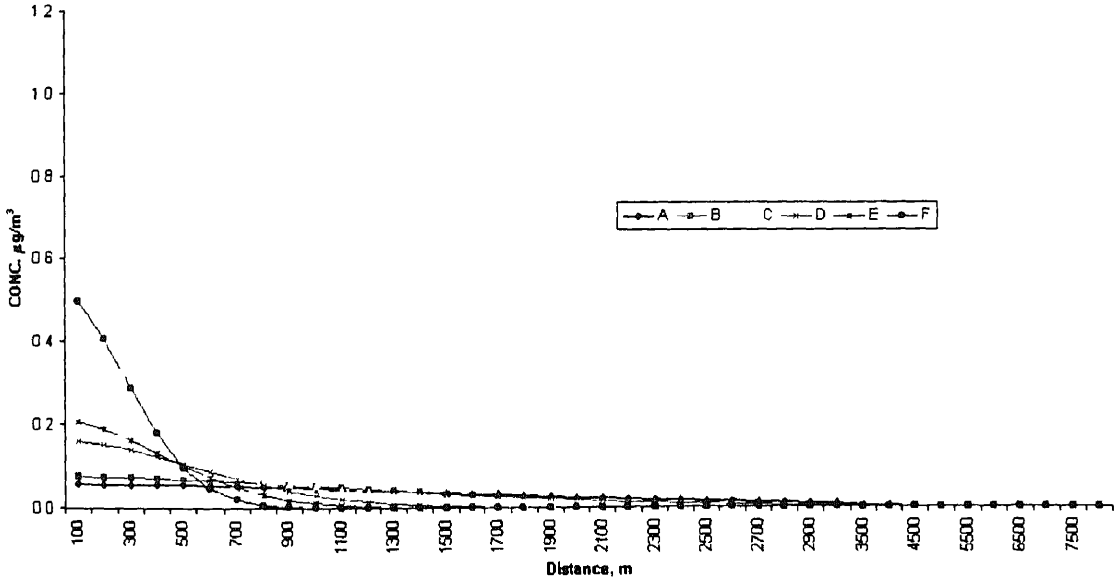


Figure 5.1c PTMTP results for VSBK-1 for the average wind speed of 3 m/s

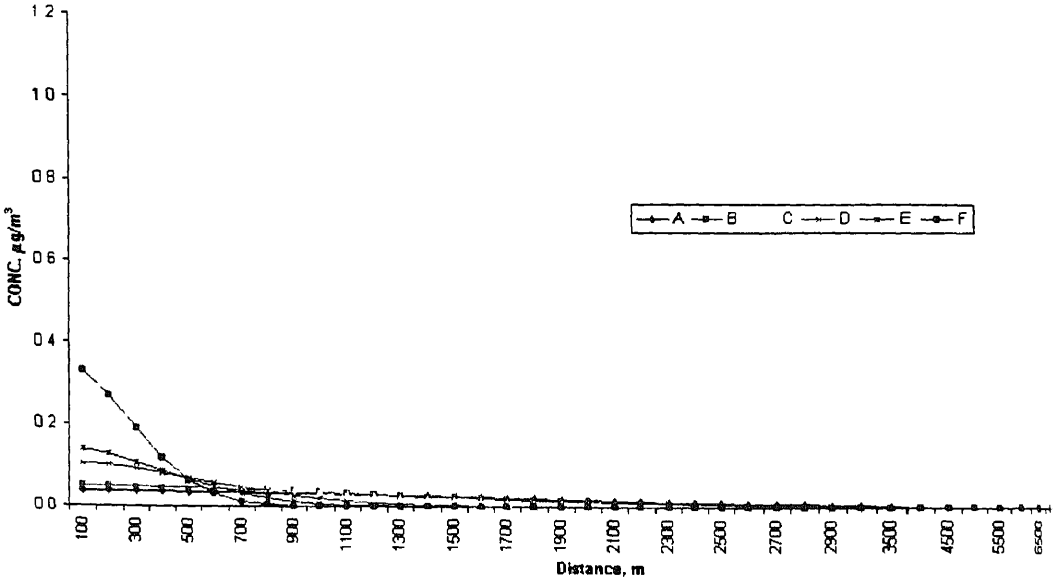


Figure 5.1d PTMTP results for VSBK-1 for the average wind speed of 4 m/s

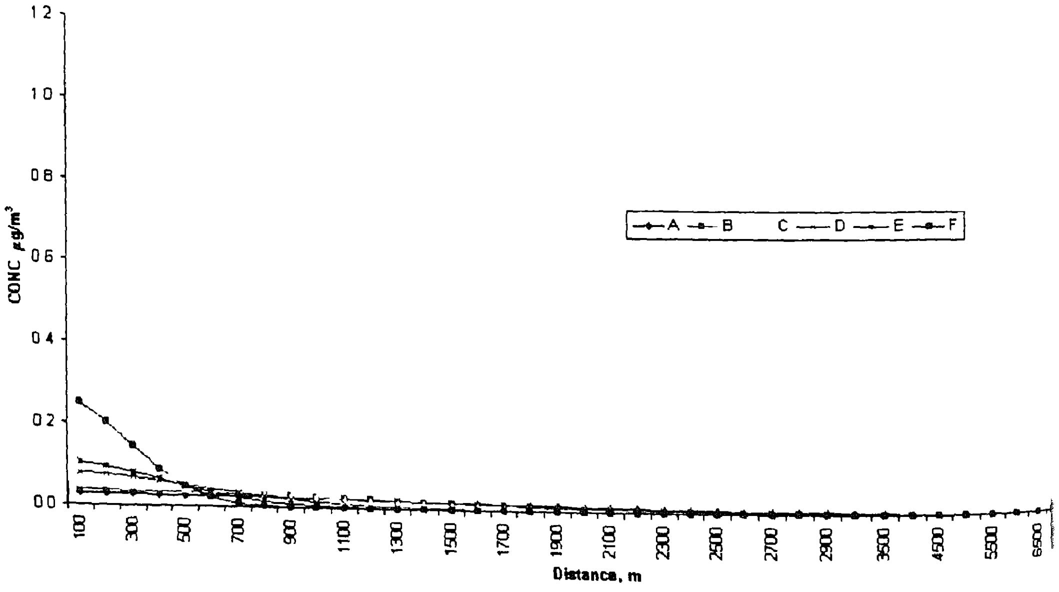
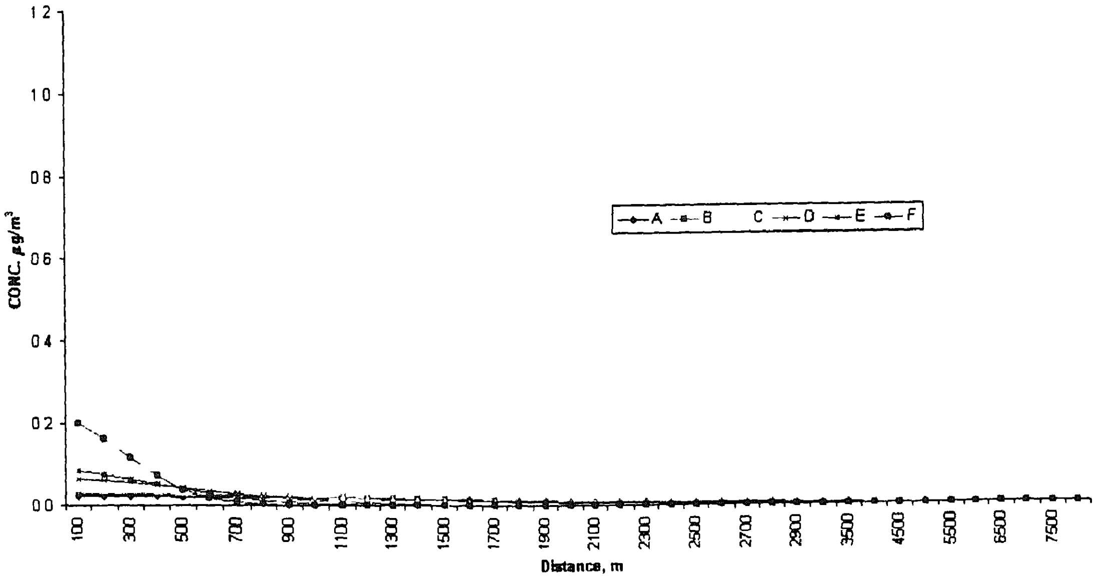


Figure 5.1e PTMTP results for Kiln-1 for the average wind speed of 5 m/s



Input Parameters

Load: 0.022g/s

Stack Height: 12m

Exit Velocity: 2m/s

Stack Diameter: 0.25m

Stack Temperature: 317K

Ambient Temperature: 313K

Maximum SPM Concentration $\mu g/m^3$ at 100m down wind at VSBK1

Stability Classes	Wind Speeds 1m/s	2m/s	3m/s	4m/s
A	0.11	0.06	0.04	0.04
B	0.15	0.07	0.05	0.06
C	0.21	0.11	0.07	0.08
D	0.32	0.16	0.11	0.20
E	0.41	0.21	0.14	0.00
F	0.99	0.50	0.33	0.00

Input Parameters	
Load, g/s	0.022
Stack height, m	12
Number of stack	6
Exit Velocity, m/s	2
Stack Temperature, K	317
Ambient Temperature, K	313

5.1.2 PTMTP model results for VSBK-2

Figures 5.2a to 5.2e show the modelling results for the VSBK 2 for different wind speeds- 1-5 m/s. For the worst dispersion scenario i.e. wind velocity of the order 1m/s, maximum GLC concentration is about 10.8μg/m^3 at a horizontal distance to 50m from the stack. The concentration tends to decrease with better dispersion on account of increased wind speeds and greater distance from the source.

Figure 5.2a : PTMTP results for VSBK-2 for the average wind speed of 1 m/s

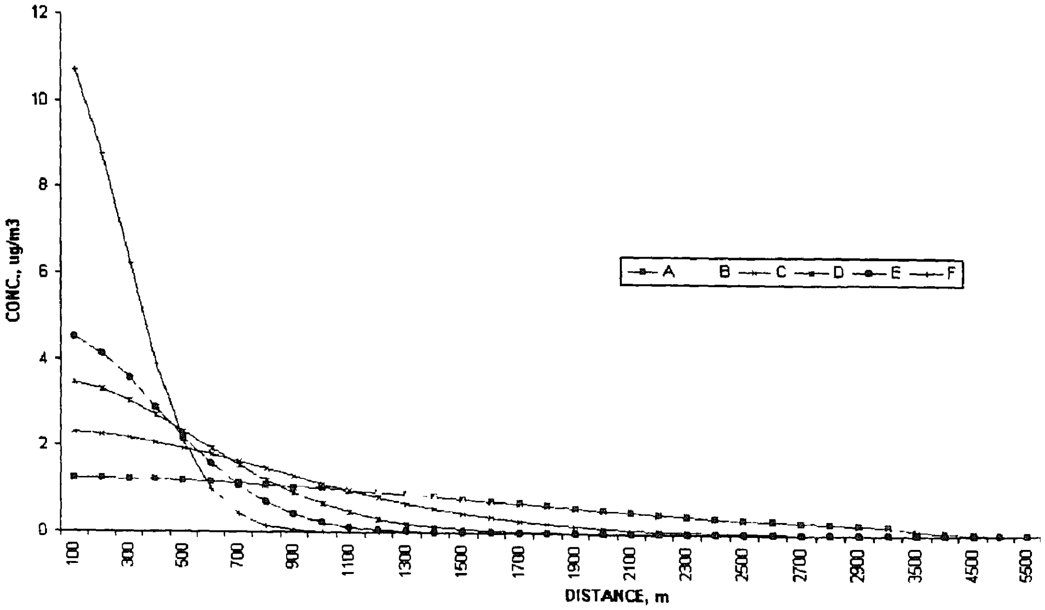


Figure 5.2b : PTMTP results for VSBK-2 for the average wind speed of 2 m/s

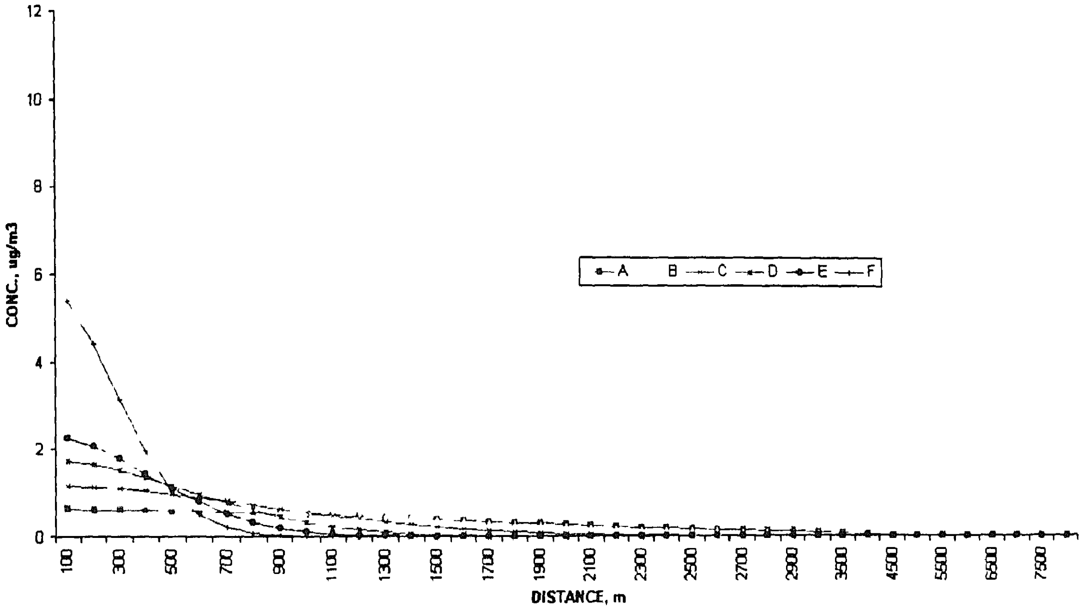


Figure 5.2c : PTMTP results for VSBK-2 for the average wind speed of 3 m/s

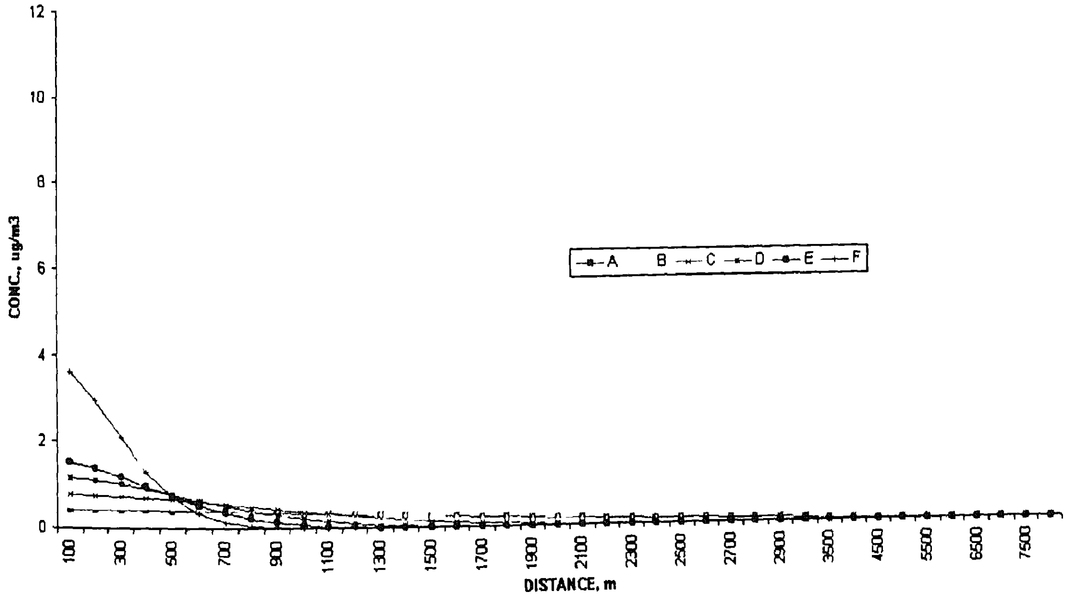


Figure 5.2d : PTMTP results for VSBK-2 for the average wind speed of 4 m/s

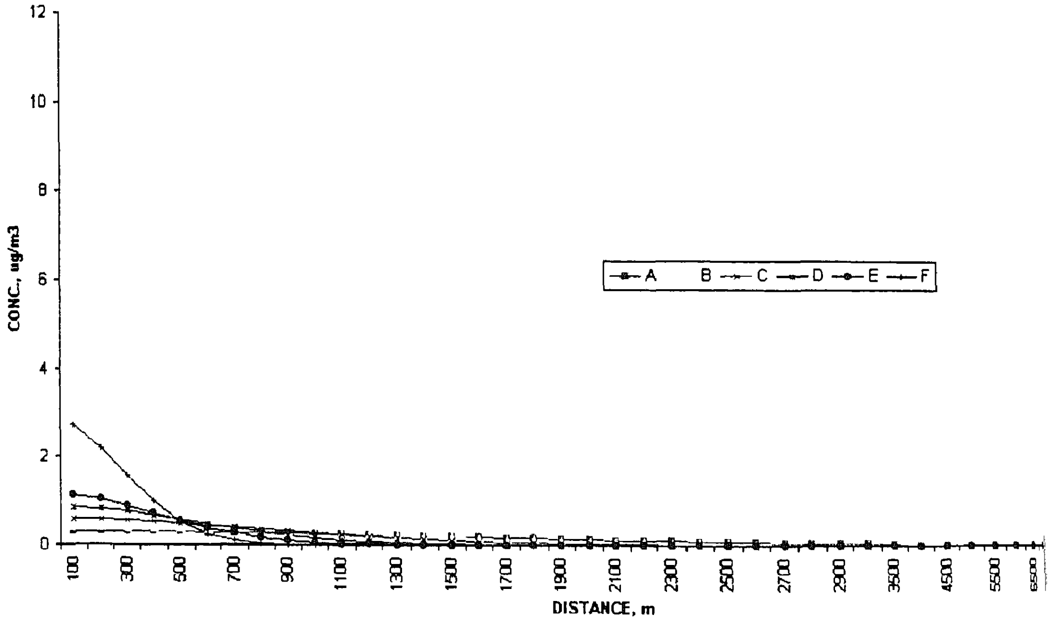
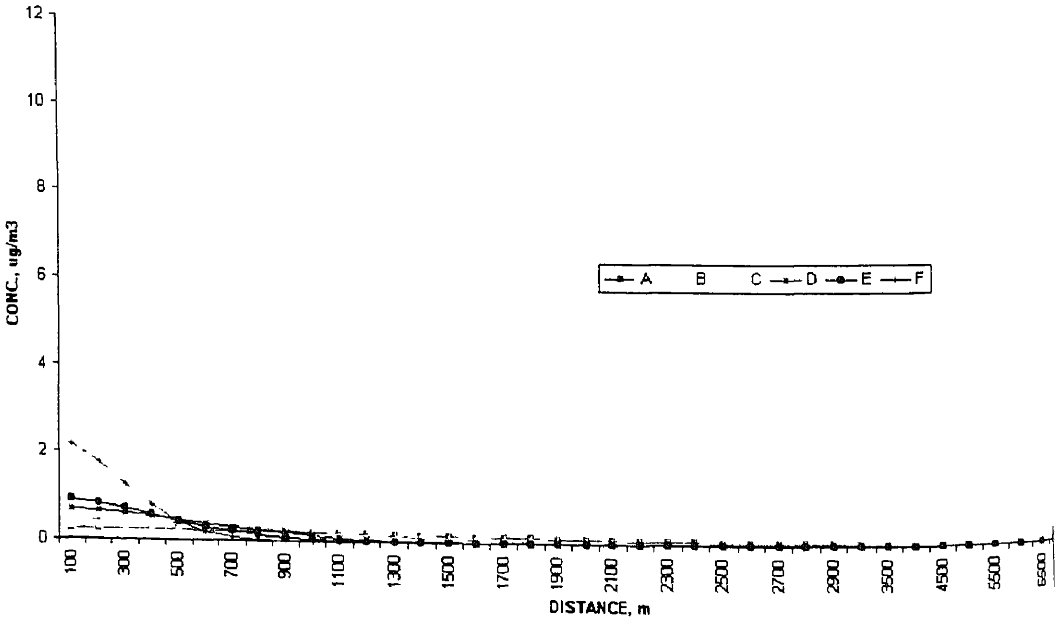


Figure 5.2e . PTMTP results for VSBK-2 for the average wind speed of 5 m/s



Maximum SPM Concentration μg/m^3 at 100m down wind at VSBK-2

Stability Classes	Wind Speeds			
	1m/s	2m/s	3m/s	4m/s
A	1.24	0.62	0.41	0.31
B	1.63	0.81	0.54	0.41
C	2.32	1.16	0.77	0.58
D	3.47	1.73	1.16	0.87
E	4.50	2.26	1.51	1.13
F	10.71	5.40	3.61	2.71

Input Parameters	
Load each Stack, g/s	0.06
Stack height, m	11.5
Number of stack	8
Exit Velocity, m/s	2.9
Stack Temperature, K	463
Ambient Temperature, K	309

5.1.3 PTMTP model results for VSBK-3

Results of computations at Kiln 3 for different wind speeds are as Figures 5.3 a to 5.3 e. As seen in the figure, even for a wind speed of the order of 1m/s, maximum incremental GLC concentration for suspended particulate matter is about 0.36 μg/m3 at a horizontal distance to 50m from the stack. The concentration tends to decrease with better dispersion on account of increased wind speeds and greater distance from the source.

Figure 5.3 a : PTMTP results for VSBK-3 for the average wind speed of 1 m/s

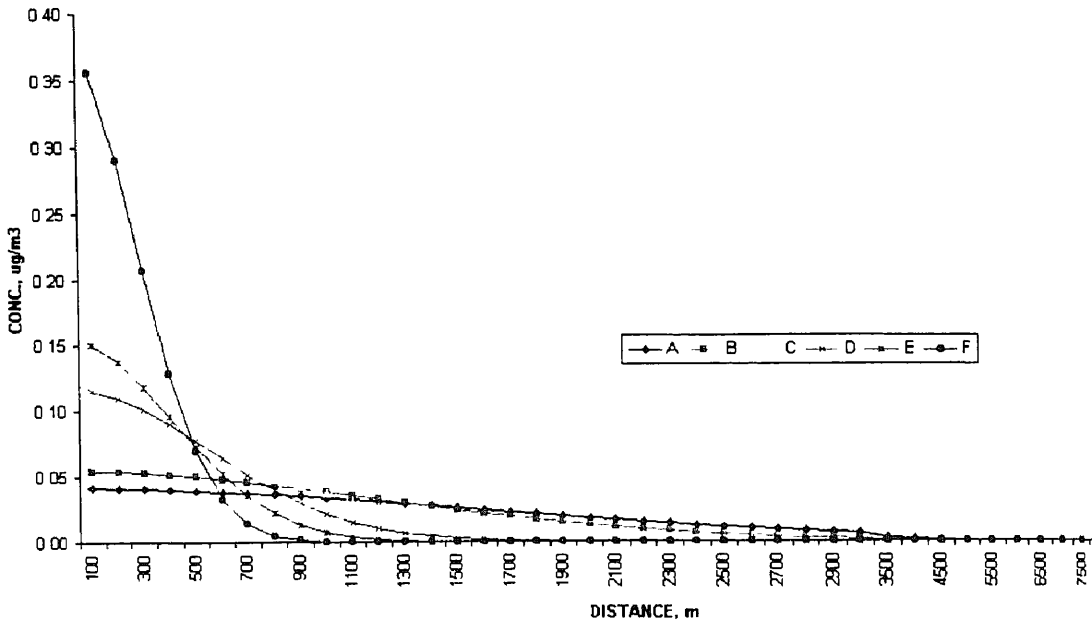


Figure 5.3 b : PTMTP results for VSBK-3 for the average wind speed of 2 m/s

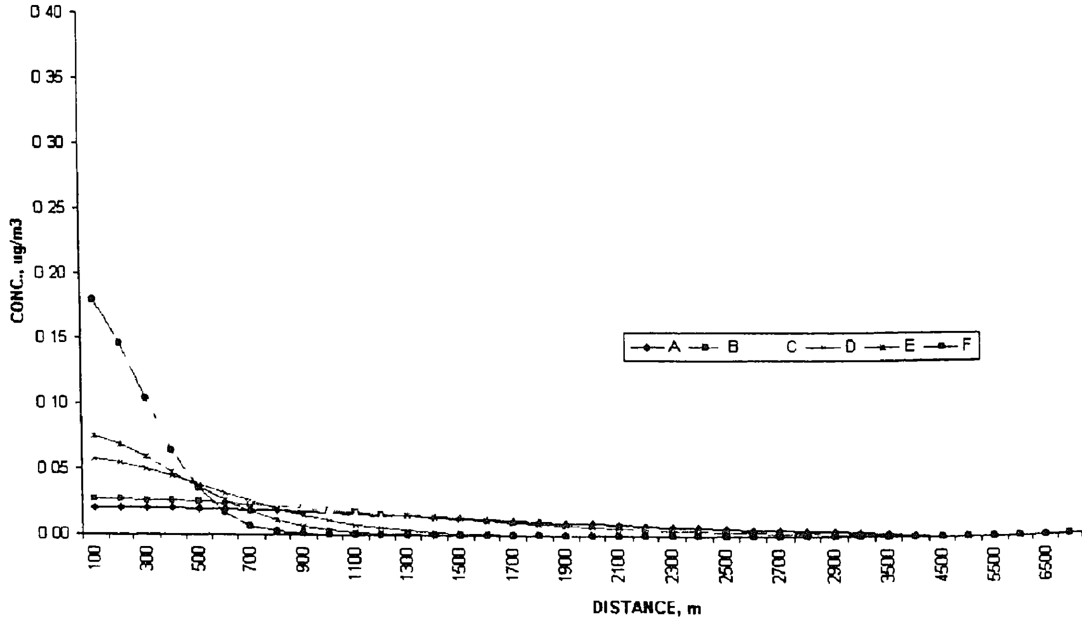


Figure 5.3c. PTMTP results for VSBK-3 at the average wind speed of 3 m/s

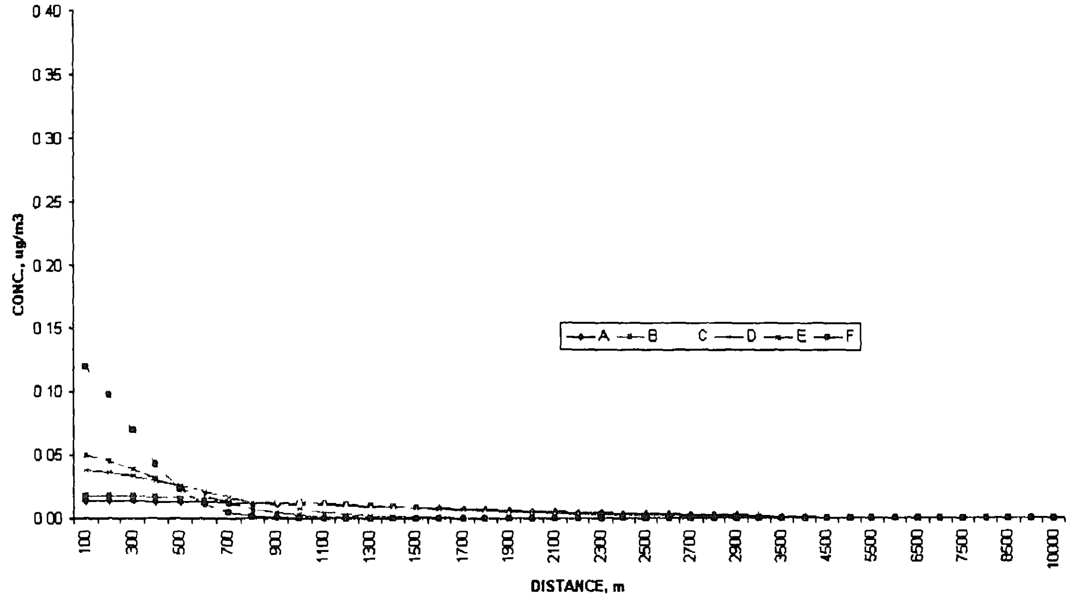
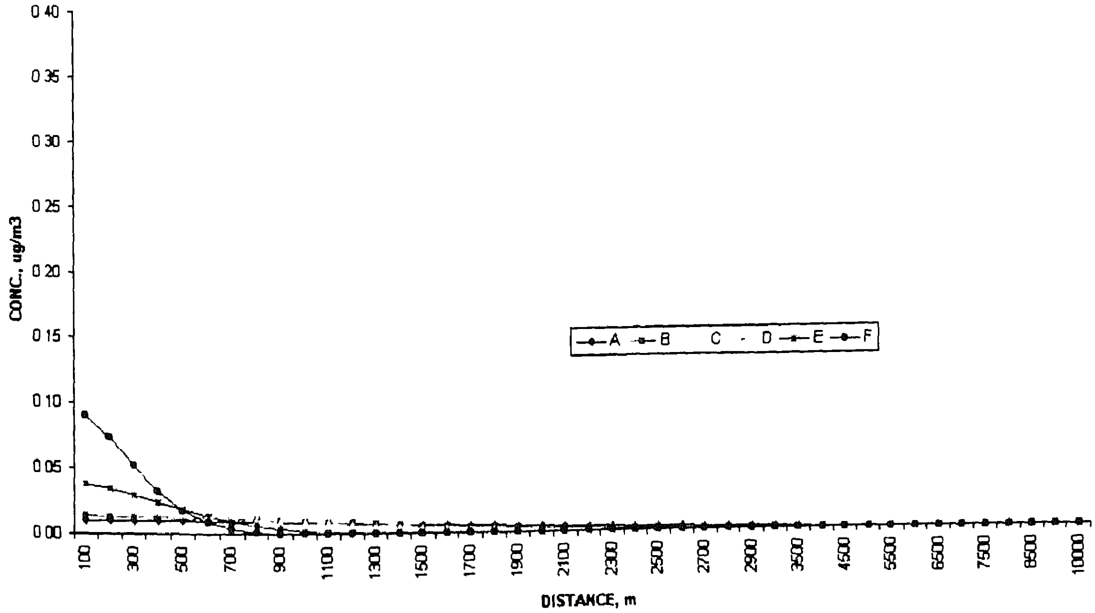


Figure 5.3d: PTMTP results for VSBK-3 at the average wind speed of 4 m/s



Maximum SPM Concentration µg/m3 at 100m down wind at VSBK-3

Stability Classes	Wind Speeds			
	1m/s	2m/s	3m/s	4m/s
A	0 04	0 02	0 01	0 01
B	0 05	0.03	0.02	0 01
C	0 08	0 04	0 03	0 02
D	0 12	0 06	0 04	0 03
E	0 15	0 08	0.05	0 04
F	0 36	0 18	0.12	0 09

Input Parameters	
Load each stack, g/s	0 008
Stack height, m	12
Number of stacks	2
Exit Velocity, m/s	1 4
Stack Temperature, K	397
Ambient Temperature, K	303

5.1 4 PTMTP model results for VSBK-4

Modelling results for the Single stack (VSBK 4) are shown as Figures 5 4a to 5.4e. These have been calculated for different wind speeds of 1-5m/s For wind speeds of the order of 1m/s, GLC is about 0 27µg/m^3 at a horizontal distance to 50m from the stack.

Figure 5.4a: PTMTP results for VSBK-4 for the average wind speed of 1 m/s

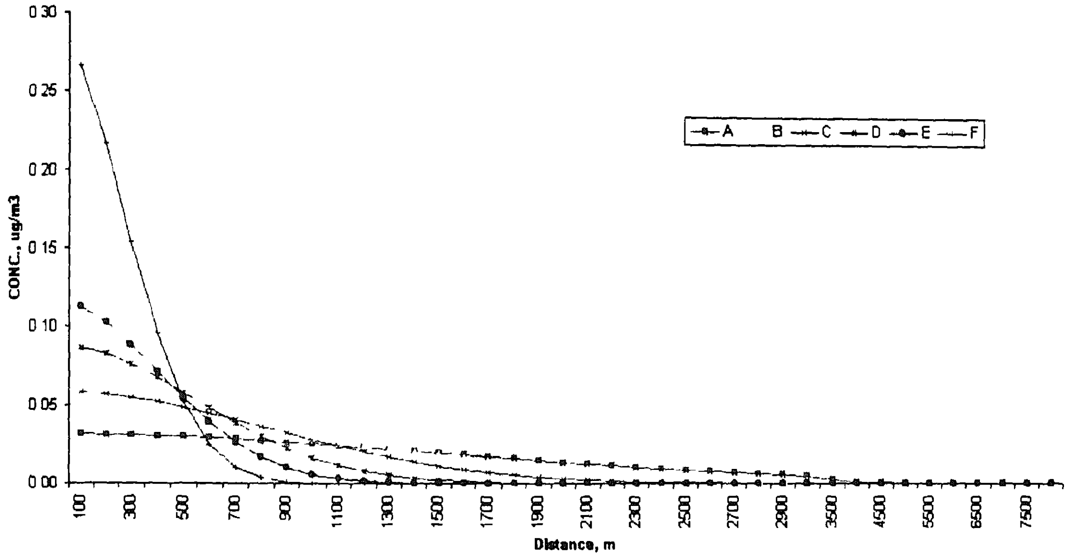


Figure 5.4b: PTMTP results for VSBK-4 for the average wind speed of 2 m/s

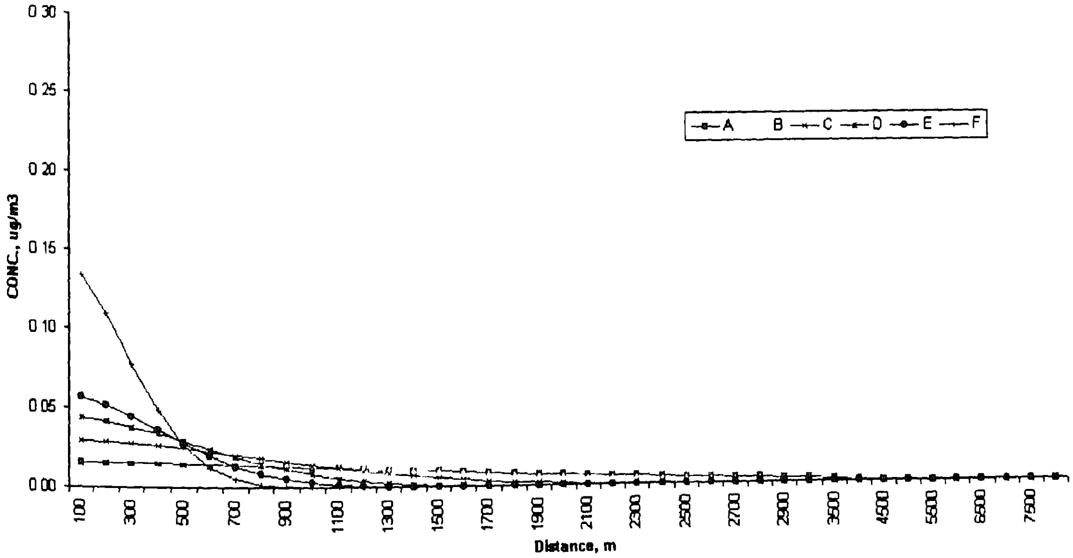


Figure 5.4c: PTMTP results for VSBK- 4 for the average wind speed of 3 m/s

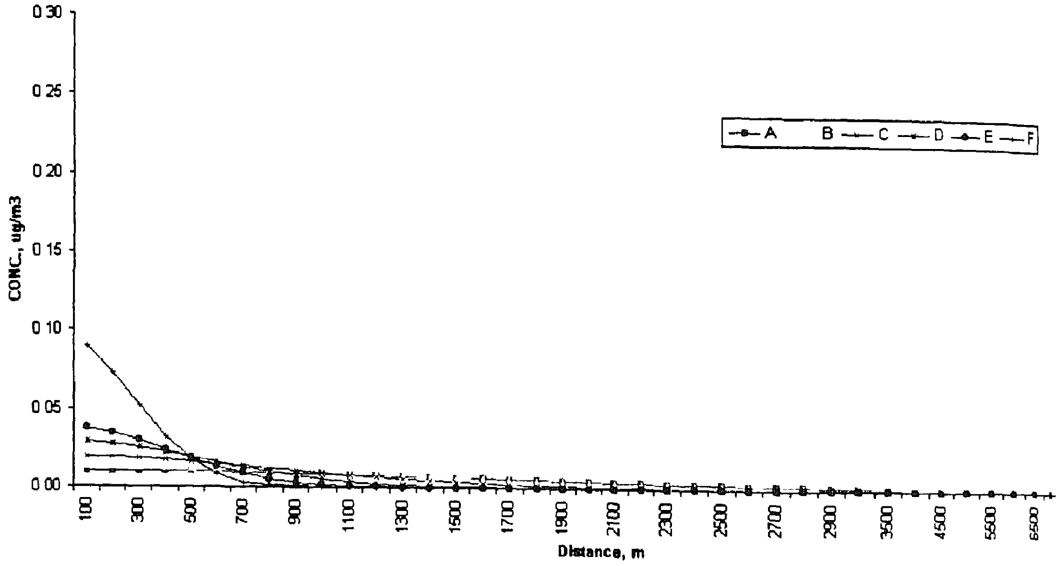


Figure 5.4d: PTMTP results for VSBK-4 for the average wind speed of 4 m/s

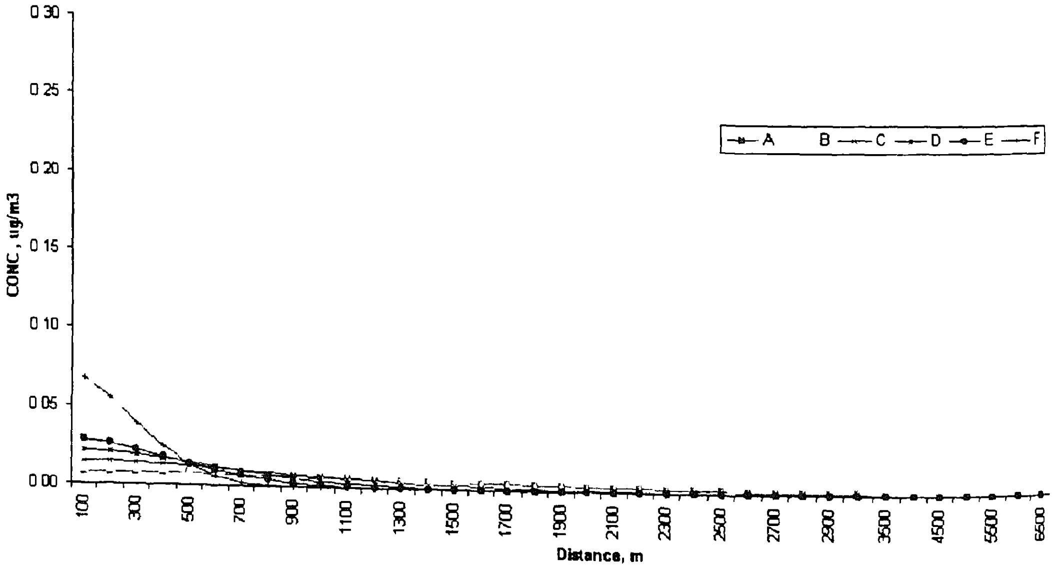
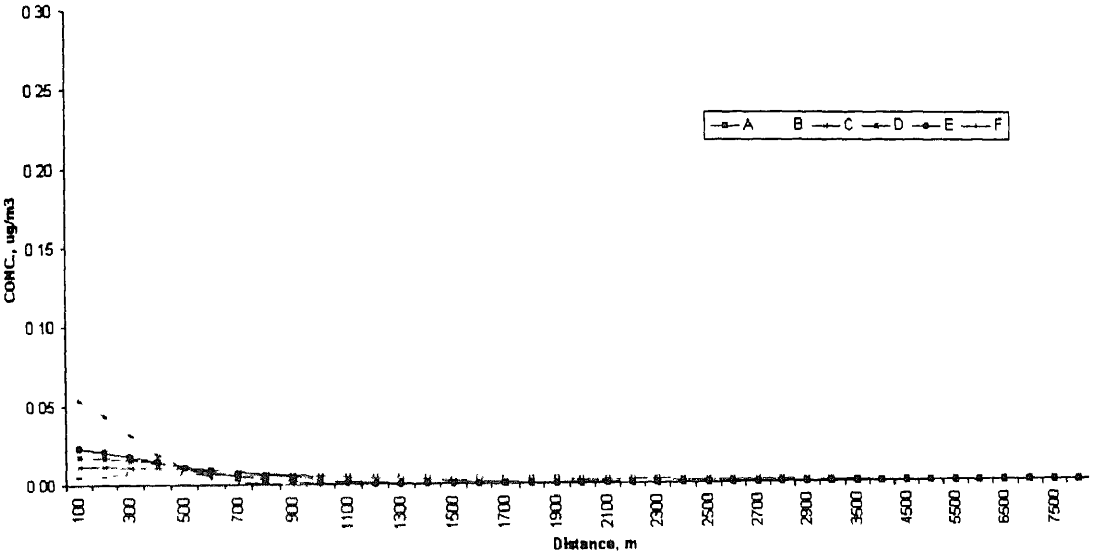


Figure 5.4e: PTMTP results for VSBK-4 for the average wind speed of 5 m/s



Input Parameters

Load. 0 012g/s
Stack Height 13m
Exit Velocity· 1 2m/s
Stack Diameter 0 25m
Stack Temperature 353K
Ambient Temperature 295K

Maximum SPM Concentration µg/m^3 at 100 m down wind at VSBK-4

Stability Classes	Wind Speeds			
	1m/s	2m/s	3m/s	4m/s
A	0 03	0 02	0 01	0 01
B	0 04	0 02	0 01	0 01
C	0 06	0 03	0 02	0.01
D	0 09	0 04	0 03	0.02
E	0.11	0.06	0.04	0.03
F	0.27	0 13	0 09	0 07

Input Parameters	
Load, g/s	0.012
Stack height, m	13
Number of Stack	3
Exit Velocity, m/s	1.2
Stack Temperature, K	353
Ambient Temperature, K	295

5.2 Discussion on results

PTMTP model was used to compute the cumulative impact of emission from the brick kilns on the Ground Level Concentrations under different meteorological conditions. The model results are summarised and shown in **table 5.2**. In all these kilns the maximum incremental rise in ground level SPM concentration is expected under the stable condition with low wind speeds.

Table 5.2 maximum incremental rises in ground level SPM concentrations (µg/m^3)

Location	Stability	Wind Speed			
		1 m/s	2 m/s	3 m/s	4 m/s
VSBK-1	F	0.99	0.50	0.33	0.07
VSBK-2	F	10.71	5.40	3.61	2.71
VSBK-3	F	0.36	0.18	0.12	0.09
VSBK-4	F	0.27	0.13	0.09	Negligible

Following conclusions are drawn from the results:

1. In all VSBKs, the maximum impact zone within which incremental concentrations are significant lies with in the downwind distance of 100 metre
2. In case of VSBK-2, where there are 8 number of stack, the maximum increase in the ground level concentration (GLC) for SPM was computed by PTMTP is 10.7 µg/m^3 at 100 metre under very stable condition at 1m/s wind speed.
3. The pollutants are dispersed well in the lower atmosphere under unstable atmosphere for all wind speed conditions, which shows a very marginal increase in GLC and it remains almost unchanged for a longer distance
4. During daytime the incremental change in the ground level SPM concentration due to VSBK is insignificant. During the night time, due to the atmospheric conditions there may be a marginal increase in the ground level SPM concentrations, which is confined to the distance of 10 metre in the down wind direction

Other significant findings are that in the case of VSBK 1(&4), where the emission levels were monitored for two different conditions i.e., two stacks in case of VSBK 1 and single stack in case of kiln 4. The results reveal that in the case of single shaft the incremental concentration was reduced by 27%. Therefore, it is felt that the single stack system could help in reducing the emissions. However, this analysis is based on monitoring of only one single stack system, which needs to be studied further.

5.3 Stack height estimation for VSBK

The minimum stack height required for the dispersion of pollutants was calculated as per the formulas recommended by Central Pollution Control Board (CUPS/13/1984-85).

Stack height H in meters for different emission rates [Q] for

Sulphur dioxide $H = 14\,(Q)^{0.3}$ [Q in kg/hr]

Particulate matter $H = 74\,(Q)^{0.27}$ [Q in tonne/hr]

The estimated minimum stack heights required for proper dispersion of pollutants are given in table 5.3

Table 5.3 Stack height estimation for the VSBKs

	SO_2 emission rate		Particulate emission rate	
Kiln	kg/h	Stack height (m)	tonne per hour	Stack height (m)
VSBK-1	0.0102	3.5	0.00008	5.8
VSBK-2	0.03	4.9	0.00022	7.6
VSBK-3	0.023	4.5	0.00003	4.4
VSBK-1	0.011	3.6	0.000044	4.9

Note: Stack height indicates height from the ground level

In all these kilns, the stack height is more than 10 meters from the ground level, which is higher than the estimated minimum stack height requirement.

6

Emission standards for VSBKs

The SPM emissions, mass emission load and specific energy consumption of VSBKs are compared with other brick making and similar firing technologies in the following sections.

6.1 Comparison with other brick kiln technologies

Moving chimney BTK, fixed chimney BTK and high draught kiln are the other types of continuous kilns in use, with which the performance of VSBK can be compared.

The important performance parameters, which are of interest while comparing the environment performance of brick kilns, are:

- Stack emissions – SPM (mg/Nm^3) as well as emission loading (g/ kg-fired brick)
- Specific energy consumption (MJ/kg-fired brick), which is an indication of the energy efficiency

The data for moving chimney BTK, fixed chimney BTK and high draught kilns (located in north zone), used in subsequent paragraphs, have been taken from CPCB document on brick kilns [a]

6.1.1 Stack emissions

The stack emissions of different brick kiln technologies are shown in Figure 6.1. In the annular kilns (BTKs and high draught), the fuel feeding is intermittent and hence emissions are measured separately for feeding and non-feeding periods as shown in the figure Higher emissions are observed during the coal-feeding period for annular kilns. However, in VSBK, there is no distinct coal-feeding period and hence emissions are not separately measured for coal feeding and non-feeding periods and hence only average values are shown against VSBK.

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[a] Comprehensive industry document with standards/ guidelines for pollution control in brick kilns, Central Pollution Control Board, New Delhi ~~(1996)~~

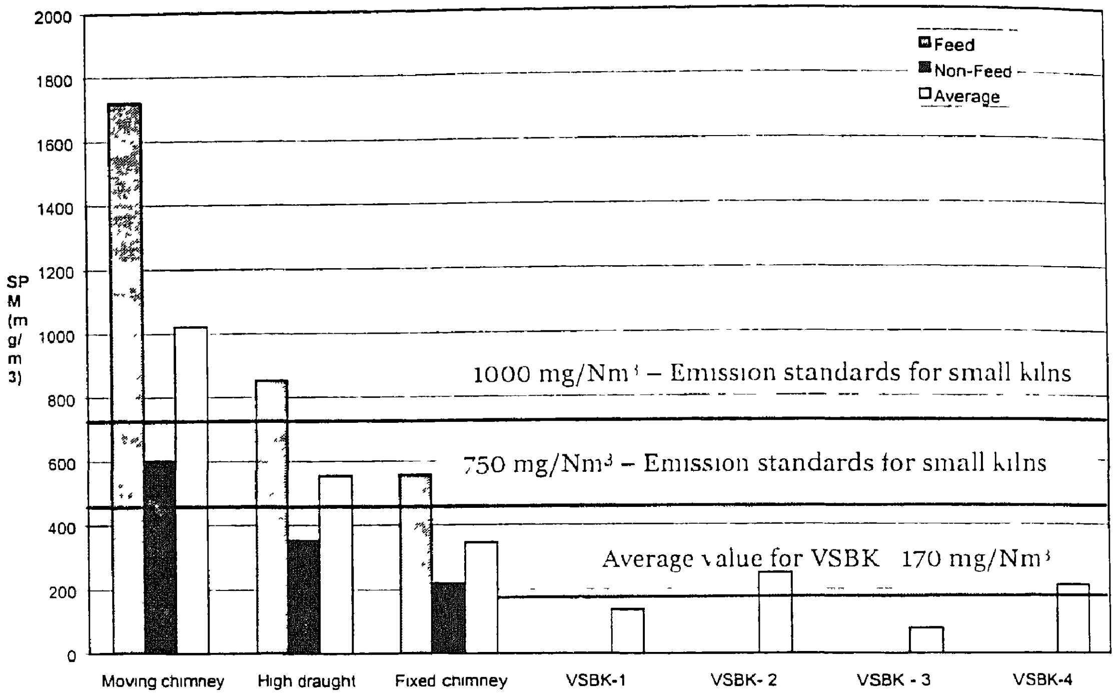


Figure 6.1 Stack emissions (SPM levels) from different brick kilns

The SPM levels show that they are highest for moving chimney BTKs (max 1721 mg/Nm^3, average: 1021 mg/Nm^3) and minimum for VSBKs (77 to 250 mg/Nm^3, average for four kilns . 170 mg/Nm^3) It may be noted that the production capacities of VSBKs match with the moving chimney BTKs of small and medium capacities and the SPM emissions are significantly lower as compared to moving chimney BTKs which have to meet the emission standards of 1000 mg/Nm^3.

The stack emissions from VSBKs are also lower compared to fixed chimney BTKs (maximum: 558 mg/ Nm^3; Average. 346 mg/ Nm^3) The comparative data for BTKs equipped with gravity settling chambers is not available.

The mass emission load of different brick firing technologies have been compared in figure 6.2 which shows that it is lowest in case of VSBK (0.11 to 0.48 g/kg fired brick), except for VSBK–2 showing 1.05 g/kg fired brick The lowest mass emission load was observed for VSBK with single chimney arrangement The monitoring was carried out in summer and winter seasons. It also indicates that the mass emission loads are lower during winter season.

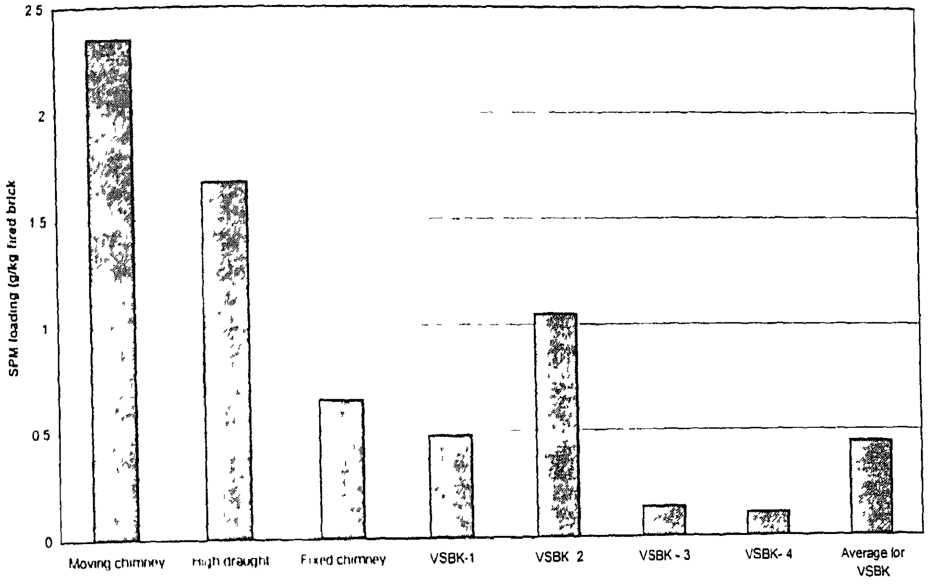


Figure 6.2 Mass emission load of different brick kilns

6.1.2 Specific energy consumption

The process efficiency is reflected in the specific energy consumption of the kiln. The specific energy consumption of VSBK technology was observed to be the lowest (0 74 to 1.07 MJ/kg fired brick) with an exception of VSBK-3 with a figure of 1 26 MJ/kg fired brick. The higher level of 1 26 MJ/kg may be attributed to the non-stabilised condition of the kiln during the period of monitoring Melting of bricks were observed which clearly indicated higher fuel input. The specific energy consumption of the VSBKs monitored is shown in Figure 6.3.

Apart from the energy monitoring carried out for this study, TERI also had carried out energy monitoring of other VSBKs as well Table 6 1 shows the specific energy consumption of other VSBKs, which clearly shows that specific energy consumption for VSBK is much lower as compared to other brick firing technologies

Table 6.1 Specific energy consumption of other VSBKs

VSBK	State	*Specific energy consumption (MJ/kg fired brick)*
VSBK -Datia	Madhya Pradesh	0.84
VSBK -Kankia	Orissa	1 06
VSBK -Pune	Maharashtra	0.85
VSBK - Varanasi	Uttar Pradesh	0.83
VSBK - Amravati	Maharashtra	0 78

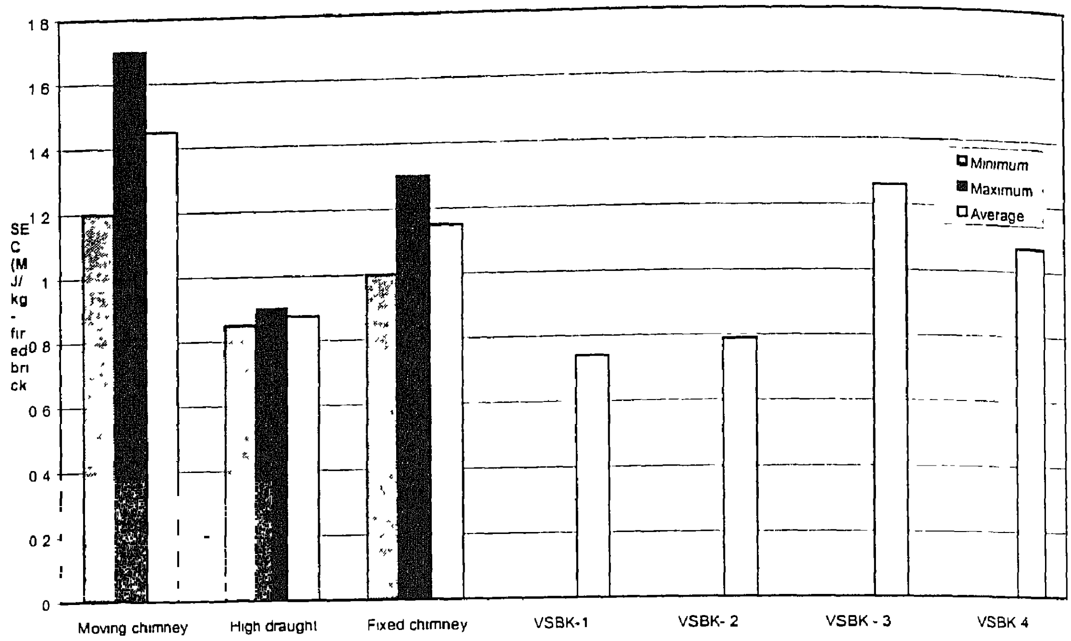


Figure 6.3 Specific energy consumption (SEC) of different brick kilns

6.2 Comparison with other products with similar firing technologies

Cupola furnace and lime kiln have similar firing technology i.e. vertical, updraught system. Emission standards are available for both the systems having different production capacities (table 6.2). The SPM emission standards for smaller production capacities of these technologies are in the range 450 to 500 mg/Nm^3.

Table 6.2 Emission standards with other similar firing technologies

Firing technologies	Production capacity	SPM standards (mg/Nm^3)
Cupola	Up to 3 tph	450
	More than 3 tph	150
Lime kiln	5 to 40 tpd	500
	More than 40 tpd	150
BTK	Up to 15000 bricks per day	1000
	More than 15000 bricks per day	750

tph – tonne per hour, tpd – tonne per day

6.3 SPM emission standards for VSBK

The measured values of SPM presented for the four VSBKs monitored during the study in table 4.1 are at different excess air levels. For comparison they were normalised against a reference O_2 concentration of 14%, using the formula:

$$SPM_{Normalised} = Y \times SPM_{mes}$$

$$Y \text{ (Normalisation factor)} = (20.9 - O_{2\text{-ret}})/(20.9 - O_{2\text{-mes}})$$

The normalised values are presented in table 6.3.

Table 6.3 Normalised SPM levels in VSBKs

	Measured (average values)			
VSBK	O_2 (%)	SPM (mg/Nm^3)	Y	SPM (Normalised) (mg/Nm^3)
VSBK-1	17.3	136	1.92	261
VSBK-2	15.5	250	1.28	319
VSBK-3	17.0	77	1.77	136
VSBK-4	14.0	212	1.00	212

The exceptionally low normalised SPM concentration observed in VSBK-3 may be attributed to use of only "internal fuel" for firing bricks at the time of monitoring, which is not a regular practice in brick kilns in the country. Therefore, VSBK-3 results may be excluded while delineating emission standards for VSBK.

The only fully commercial large-capacity VSBK covered in the study was VSBK-2, which shows the highest normalised SPM concentration (exceeding 300 mg/Nm^3) in stack gases. The other two cases, VSBK-1 and 4 pertain to VSBK operating under controlled conditions (project kiln operating under the supervision of experienced supervisors). For VSBK-1 the normalised SPM concentrations is above 250 mg/Nm^3, while for VSBK-4 it is below 250 mg/Nm^3. These values could be considered as minimum achievable SPM concentration levels in the present VSBK configuration.

Therefore, SPM concentration of 250 mg/Nm^3 (at 14% O_2 concentration) in stack gases is proposed as minimal emission standard for vertical shaft brick kilns (VSBKs).

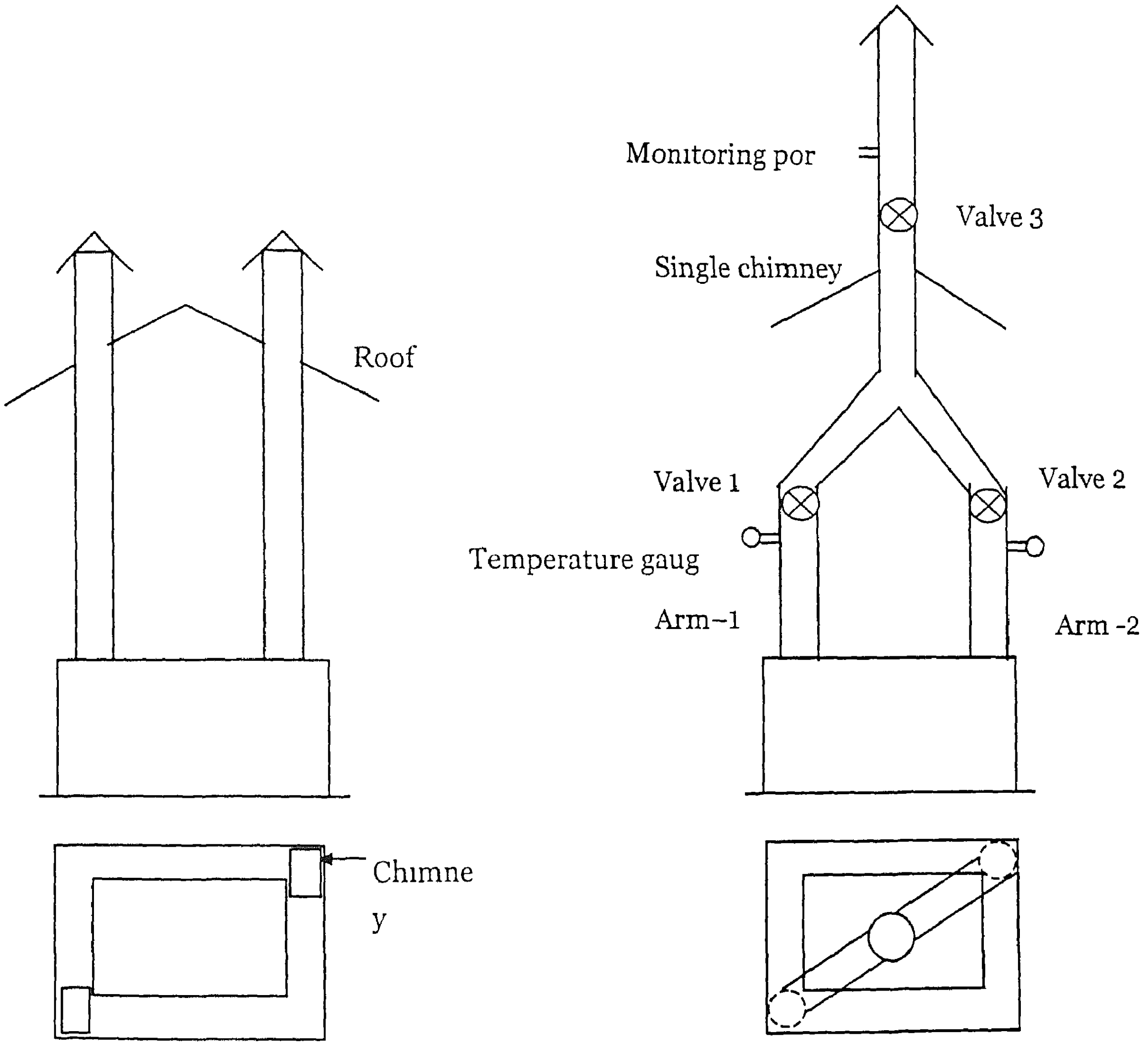
6.4 Stack height standards for VSBK

Stack height estimations for VSBK, based on measured SO_2 and SPM emission rates (section 4.4), show that the maximum stack height requirements for VSBK varies between 3.5 to 7.6 metre. In all the four kilns monitored, the sulphur content was less than 1%

A worst-case scenario was built up assuming that high sulphur coal (5% sulphur) is burnt in VSBK and all the SO_2 generated leave through the stack. The minimum stack height requirements work out to be 13.5 metre. However, it may be noted that the high sulphur content coal is not suitable for firing in VSBK as the coal contains high percentage of volatile matter.

- Based on the monitoring and meeting the requirements of environmental standards, it is recommended that the stack height of VSBK should not be less than 14 metre from the natural ground level.
- Keeping in view the requirements of environmental regulatory authorities for monitoring stack emissions, only one chimney per shaft of VSBK should be preferred.

A sketch of one type of single chimney system (monitored at VSBK-4) is shown in **figure 6.4**. In this arrangement, chimney is made of metal (mild steel). The two chimneys emanating from the shaft top are joined together to form a single chimney arrangement Valves (dampers) as well as temperature gauges are provided in both the arms.



Existing double chimney arrangement

Figure 6.4 Single chimney system for VSBK

6.5 Pollution control system requirements

The environmental and energy monitoring of VSBK systems indicates the following features with regard to VSBK technology:

- *Lower SPM emissions.* The average SPM level from VSBK stacks is 170 mg/Nm^3 and the highest emission observed was 250 mg/Nm^3 which is very much lower than the existing stringent environmental standards for brick kilns i.e. 750 mg/Nm^3 (section 6.1.1)
- *Lower mass emission loads.* The mass emission loads of VSBKs are also significantly lower (average 0 45 g/kg fired brick) than other existing technologies for brick kilns (0.65 to 2 35 g/kg fired brick) except for one kiln (section 6.1.1).
- *Marginal increase in ground level SPM concentrations.* The increment in ground level concentration predicted with environmental model shows that the there is marginal increase in ground level concentration of dust level (about 10 $\mu m/Nm^3$) at a distance of 100 metre downwind direction (section 5.2).

Incorporation of pollution control system is not necessary for VSBKs keeping in view the lower emission load of pollutants and technical difficulties in incorporating any pollution control system in the natural draught system operating at very low draught.

6.6 Guidelines for improving environmental performance of VSBK

A set of guidelines which would help in bringing down emission levels in VSBK are given below:

Fuel

1. Use of internal fuel

Use of internal fuel during brick moulding helps in reducing stack emissions, particularly suspended particulate matter (SPM).

- Experiences in VSBK operation in India show that fuels such as coal powder, boiler ash, fly ash and biomass fuels (ricehusk, sawdust) can be effectively used as internal fuel in VSBKs.

- The amount of internal fuel addition in green[a] brick during moulding[b] depends on the quality of soil and the desired quality of the fired product. It is generally observed that addition of internal fuel in soil varies between 1% to 10% (by weight) Fly ash is used as internal fuel in one of the VSBKs (Nimbut in Maharashtra) upto the extent of 8–9% by weight.

2. Characteristics of external fuel

- Low volatile content bituminous coal with low sulphur content is preferred The properties of coal, recommended for use in VSBKs, are shown in **table 6.4**

Table 6.4 Properties of coal used in VSBK (on dry basis)

Volatile matter	15 – 25%
Ash	25 – 45%
Fixed carbon	35 – 45%
Gross calorific value	4000 – 5500 kcal/kg [or] 17 – 23 MJ/kg
Sulphur	Less than 1%

- Use of fuel having volatile matter more than 25% is likely to result in higher fuel consumption as well as higher emissions (soot, unburnt carbon and CO)

3. Firing of perforated bricks

- Firing of perforated bricks will help in reducing the fuel consumption and emissions per unit of production. It will also lead to reduced consumption of soil Perforated bricks have been successfully fired in VSBKs.

4. Use of shaft lid

- It is recommended to use shaft lid (**figure 6.5**) with proper sealing[c] arrangement at shaft top. This will help in reducing the concentration of pollutants in the loading platform.

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[a] Green brick – Just moulded brick before drying

[b] Addition of internal fuel requires proper mixing of soil for uniform distribution across the brick

[c] After each loading, the shaft top is covered with the lid (usually made of mild steel) over the frame fixed on it. Sand sealing is quite effective which has been demonstrated and used in VSBK.

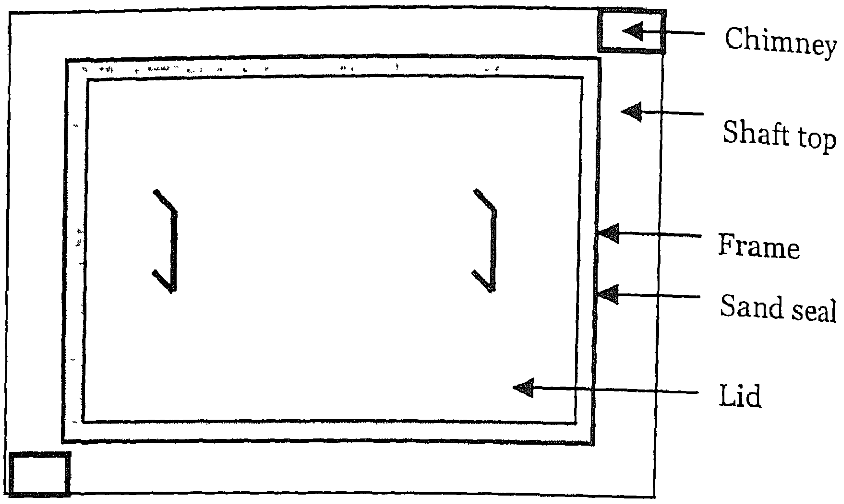

Figure 6.5 Arrangement of shaft lid

5. Location of firing zone

The location of firing zone should be kept close to the middle of the shaft length. If the fire moves down, it would affect the product quality If the firing zone moves up, it would lead to increase in level of CO, hydrocarbon emissions

6. Instrumentation

For monitoring and controlling of operation, the VSBK unit would require (i) 2 to 3 thermocouples (with a range of about 1100°C) for measuring temperatures in the shaft, and (ii) 2 number of temperature gauges (upto a range of 250°C) for monitoring the flue gas temperatures in the chimneys

7. Proper ventilation arrangements

(i) Loading and storage platform

Proper ventilation arrangements by providing sufficient opening on all sides of the loading platform , monitor roof, limiting green brick stacking to a height of about 1 5 m at the loading platform ensures good ventilation at the loading platform and reduces the exposure of workers to pollution

(ii) Cooling chamber

Provide proper ventilation at cooling chambers[a]. The cooling chambers are extended arrangements at the unloading side of VSBK. At lease two persons are involved in the unloading operation which is carried out for a period of 15 minutes Upon cooling of fired bricks in the trolley, bricks are removed for stacking. Proper ventilation at this level is important for this purpose

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[a] Cooling chambers are used in most of the VSBKs to allow for slow rate of cooling of unloaded fire bricks which otherwise will lead to cracks in the fired bricks due to faster cooling rates.

8. Paving of floor, regular cleaning/sprinkling of water at unloading side

Paving of floors is recommended at the unloading side which will help in avoiding sand dust where there is a regular movement of workers who do the unloading operation Regular cleaning and water sprinkling of floor at unloading side is recommended The cooled unloaded bricks in the trolley are shifted in rails Ash from burnt coal will be lying with each batch[a] of unloaded bricks. Removal of ash falling on the ground while taking out the bricks will help in avoiding the dust level at the unloading side.

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[a] Each batch of bricks in VSBK generally contains four layers of bricks with coal being spread between the brick gaps

7 Conclusions

7.1 VSBK technology

A comparison covering both technical and economic aspects of VSBK and BTK kilns of similar capacities for Gwalior is presented in table 7.1.

Table 7.1 Comparison of VSBK and BTK at Gwalior

S No	Data/ information	VSBK	BTK
1	System description	6-shaft VSBK with each shaft of 1 m x 2m	Fixed chimney system
2	Production capacity (bricks per day)	30,000 to 36,000	25,000 to 40,000
3	Investments for kiln construction (materials, wages, consultancy)	Rs 15 lakh	Rs 10 lakh
4	Coal consumption (per lakh bricks) (GCV of coal = 5000 kcal/kg)	10 to 11 tonne *	14 to 18 tonne
5	Quality of bricks		
	▪ Class-1	80-84%	65-70%
	▪ Class-2	8-10%	20-30%
	▪ Class-3	-	3-5%
	▪ Broken bricks	8-10%	2-5%
6	▪ Manpower requirements for firing	24	6
	▪ Wages (per month)	Rs 60,000	Rs 12,000
7	Land requirements for kiln construction	400 to 500 sq. m	2000 sq m

* In practice 5-6 tons of coal (external fuel) and 8% by weight boiler ash (internal fuel) is used. These have been converted into equivalent coal for direct comparison with BTK

The data presented in table 7.1 is region specific and pertain only to Gwalior. Very large diversity is found across different geographical regions in terms of quality of raw material used for brick making (soil and fuel), skills, labour cost, market price of bricks and the quality of bricks produced. Hence similar comparative statements comparing VSBK technology with other firing technologies would have to be prepared separately for different geographical regions. The experience so far indicates that the data related to fuel consumption, manpower and area requirement for VSBK technology show little variations across different geographical regions Other parameters (particularly those related with quality of fired bricks, production capacity, wages) show large variations. For example it has been observed that the production capacities of VSBK are lower compared to Gwalior (by 30-40%) with soils having high vitrification temperatures (> 1000 °C such as found in Indo-Gangetic plains). Problems have also been encountered in producing very good quality bricks in VSBKs in the Indo-Gangetic plains.

In an overall analysis it appears that VSBK is one of the viable options for firing of bricks in decentralised small-scale production in India. The positive features of the technology are:

1 High fuel efficiency, with average fuel savings of about 20% compared to BTKs and 50-60% compared to clamps (refer 6.1.2)
2 Lowest pollution (SPM) levels (refer 6.1.1)
3. Lower fugitive emissions (refer 4 2) and cleaner working environment (refer 4.3)
4. Consistency in fired brick quality (refer table 7 1)
5. Requires less space (space saving of about 60% compared to BTK) for kiln structure (refer table 7.1)
6 Kiln structure is weather protected and hence VSBK can be operated even during rainy season hence extending the brick firing season.
7. Provides flexibility in production. The kiln can be easily started and stabilizes within a very short time and hence, depending on market demands and raw material availability and the production can be varied
8. Compact layout and hence the unit resembles industry setup

On the other hand some important barriers in wide scale dissemination of the technology are:

1. Marginally higher cost of construction as compared to other traditional kilns (e g. fixed chimney BTK-refer table 7 1)
2. Requirement to lift dry green bricks to the top of the kiln shaft for loading into the kiln. The present practice of using animals or manual labour for lifting of bricks involves lot of drudgery, significant labour costs and also causes damage to green bricks The use of electricity operated hoists has been successfully tried but requires additional capital investment and availability of electricity at site Hence, development of alternate less labour intensive lifting techniques is required.

3 VSBK is a fast firing system, compared to total firing time of 12-15 days in BTKs, in a VSBK bricks are fired in 20-40 hours. To obtain good results, this fast firing process requires continuous monitoring and quick action and hence requires training of workers and changes in the traditional management practices (which at present are meant for slow rate of operation) employed at brick kilns.

4. VSBK provides less flexibility in terms of choice of fuels that can be used in the kiln. While a variety of biomass fuels and coal can be used in BTKs and clamps, in a VSBK only coal can be used as external fuel. Though it has been shown in the field that a variety of powdery fuel e g. rice husk, boiler ash, fly ash, chopped straw can be successfully used as internal fuel in VSBK.

A set of guidelines for improving the environmental performance of VSBK is presented in section 6 6.

7.2 Recommendations for emission standards for VSBK

Based on the detailed monitoring of VSBK kilns, air quality dispersion modelling exercise and taking into consideration practical aspects, following emission standards can be considered for VSBK.

- Maximum concentration limit of 250 mg/Nm^3 for SPM in flue gases in chimney at 14% O_2 concentration level (please refer to section 6 3)
- It is recommended that the stack height of VSBK should not be less than 14 metre from the ground level (please refer to section 6.4) Keeping in view the requirements of environmental regulatory authorities for monitoring stack emissions, only one stack per shaft is suggested for the VSBK
- Keeping in view the lower emission load of pollutants (dust and SO_x) of VSBK and technical difficulties in incorporating any pollution control system in natural draught system operating at very low draught, incorporation of pollution control system in not being recommended for VSBKs.

Apart from the above specific recommendations, following general features may also be considered for VSBK technology.

7.2.1 Provision of lightning arrester

- Since VSBK is a tall structure, it is also suggested to incorporate suitable lightning arrester.

7.2.2 Location of kiln

- In view of government actions such as industrial estate planning, site specification for air polluting industries etc to control air pollution, following specifications may be recommended for installation of new VSBKs.
- VSBKs should be established preferably at least 500 meters away from residential areas and fruit gardens.
- Installation of VSBKs should not be allowed in sensitive areas as notified by State Pollution Control Board under National air quality standards
- To avoid clustering of brick kilns in a locality, the distance between two kilns should be more than 1 km.

Energy performance of VSBKs

VSBK-1

The VSBK-1 is located at around 5 km distance from Datia town on Jhansi-Gwaliar road in Madhya pradesh It is being managed by the Development Alternatives, one of the partner organization in the India brick project The three shaft kiln was constructed in the year 1999-2000 The salient features of the VSBK are shown in table **4.1.1.**

Table 4.1.1 Salient features of VSBK-1 (May 2001)

Feature	Detail
Numbers of Shaft	3
Shaft cross section	Shaft 1&2 – 1 25m X 1 75 m, shaft3 – 1m X 1 5 m
Shaft height	Equivalent to 12 batches of bricks (5 3 m),each batch has four layers of bricks
Numbers of chimenys	Two masonry per shaft
Internal chimney cross section	170 mm x 410 mm
Chimeny height	About 5 m above the shaft top
Flue gas inlet levels to the chimeny	2 (12th and 10th batch)
Unloading mechanism	Single screw system

Specific energy consumption

Energy performance of one bigger shaft (1 25m x1 75 m) was monitored in VSBK-1 Internal fuel in the form of fine coal ash(bottam ash from boilers) is added to clay during clay preparation The quantity of coal ash is 6% by weight,which translate into about 200 kg/1000 bricks In addition crushed coal (particle size less than 15 mm) is sprinkled of every layer of green bricks during loading of bricks in the kiln At the time of monitoring, about 21 kg of coal sample collected from the site as found to be 5460 kcal/kg and the gross calorific value of coal ash was taken as 990 kcal/kg In energy terms the specific energy consumption was found to be 0 74+_0 04 MJ/kg of fired brick.Details regarding fuel consumption and specific energy are given in the **table 4.1.2.**The specificenergy consumption is considerably lower than the specific energy consumption of about 2 0MJ/kg fired brick of clams around Datia

Table 4.1.2 Specific energy consumption of VSBK-1

Parameters	Value
Grosscalorific value of coal	5460 kcal/kg
Grosscalorific value of coal ash	990 kcal/kg
Coal consumption (per 1000 bricks)	58 kg
Coal ash used (per 1000 bricks)	200 kg
Average Weight of fired brick	2 8 kg
Specific energy consumption	0.74 ± 0 04 MJ/kg of fired brick

Energy balance

The various elements of energy balance are as follows

- Energy inputs it is determined by adding energy inputs from all sources i e, External fuel and combustible material present in the green bricks.
- Sensible heat loss in flue gasses The hot gasses going out of chimney are at a higher temperature compared to the ambient temprature The calculation of this component requires measurement of oxygen or carbon dioxide percentage and temperature of the flue gas, quantity and ultimate analysis of fuel, and determination of specific heat of fuel gases
- Residual heat loss from fired bricks, unload bricks are at higher temperature than the ambient tempretature, giving rise to the sensible heat loss in fired bricks In a VSBK this heat loss can be substential Tempretature of bricks at the time of unloading fired bricks as the production rate are necessary for determination of this loss
- Energy required for drying of bricks The green bricks loaded into the kiln contain residual moisture. The removal of moisture requires energy Calculation of this component requires determination of the average moisture content in green bricks.
- Energy required for irreversible chemical reactions Chemicals reactions associated with dissociation of clay molecules, removal of chemical water, and decomposition of calcium carbonate are endothermic in nature The required for irreversible chemical reactions can be estimated by determining the pure clay fraction in the brick clay. Loss on ignition in the clay sample is used for determining the pure clay fraction in the clay
- Surface heat loss: The surface heat loss from the VSBK has two components One is the steady state heat loss from the klin surface and the other is the heat loss exposed hot bricks at the bottom of the shaft

Some important kln parameters used for calculation of various energy balance components are presented in **table 4.1.3.** The balance for the VSBK-1based on the measurement taken during the monitoring is presented in the **table 4.1.4**

Table 4.1.3 Important operating parameters of VSBK-1

Parameters	
Average temperature of flue gas (measured at port-hole in the chimney)	80 °C
Average temperature of unloaded bricks	123 °C
Estimated pure clay fraction in brick clay	32 %
Average moisture content green bricks	3.5 %

Table 4.1.4 Energy balance of VSBK-1

Energy balance components	Percentage
Sensible heat loss in flue gas	17.6
Potential heat loss due to 'CO' in flue gas	3.5
Heat for free moisture removal (drying of bricks)	12.8
Sensible heat loss in unloaded bricks	9.7
Heat for chemical reactions	43.2
Structure and surface heat loss (by difference)	13.2
Total heat input-0.74 MJ/kg of fired brick	100.0

VSBK-2

The klin is situated outside Gwaliar town. The four-shaft VSBK[1] is operational since 1998-99. The klin has four shafts each of 1m x 2m cross –section. The productioncapicity of the unit (four shaft combined together) is around 15000-18000 bricks per day.

Specific energy consumption

Energy performance of one shaft of VSBK-2 was monitored. Internal fuel in the form of fine coal ash is 6% by weight, which translate into about 200 kg per 1000 bricks. In addition crushed coal (particle size less than 15 mm) is sprinkled on every layer of green bricks during loading of bricks in the klin. At the time of monitoring, about 18 kg of coal was being added per batch (292 bricks) of bricks. The gross calorific value of coal sample collected from the site as found to be 5040 kcal/kg and the gross calorific value of coal ash was taken as 999 kcal /kg. In energy terms the specific energy consumption was found to be 0.79±0.04MJ /kg of fired brick**(table 4.1.5).**

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[1] Two shafts have been added during last season and now it is 6-shaft VSBK

Table 4.1.5 Specific energy consumption of VSBK-2

Parameters	Value
Calorific value of coal	5040 kcal/kg
Calorific value of coal ash	990/kcal/kg
Coal consumption (per 1000 bricks)	61.6 kg
Coal ash used(per 1000 bricks)	200 kg
Average weight of fired brick	2 7 kg
Specific energy consumption	0.79 ± 0 04MJ/kg of fired brick

VSBK-3

The VSBK-3 ic located it Nimbut about 60 km distance from Pune, Maharashtra It is owned privately It is a single shaft klin and fires extruded bricks The salient features of the klin are shown in **table 4.1.6.**

Table 4.1.6 Salient features of VSBK-3

Feature	Details
Numbers of shafts	1
Shaft cross section	1 92m x 0 96m
Number of chimneys	2
Internal chimney cross section	230mm x 310mm
Chimney height	About 10 85 m from ground level
Unloading mechanism	Single screw system

Specific energy consumption

The kiln was using about 67% and 25% fly ash for brick making Internal fuel (coal dust) is added which is 3% by weight, translating into 65 kg per 1000 bricks The external fuel used is coal About 21 kg of coal is added in3 layers in each batch (324 bricks) during loading However it may be noted that the klinwas not stablised during the time of monitoring as large amounts of melting of bricks was observed which could be attributed to the unmeasured quantity of coal dust used as internal fuel in green dry bricks A tempreture of 1028-1047 °C was observed in the firing zone during monitoring which is well above the tempreture requirements of soil available at Nimbut
The gross calorific value of coal sample collected from the site as found to be 4770 kcal/kg and the gross calorific value of coal powder was 4270 kcal/kg The fly ash had a gross calorific value of 530 kcal/kg In energy terms the specific energy consumption was found to be 1 26 MJ/kg of fired brick (table 4 1 7) The specific energy consumption is found to be higher mainly due to higher fuel inputs, which had come down klin stabilization

Table4.1.7 Specific energy consumption of VSBK-3

Parameters	
Gross calorific value of coal	4770 kcal/kg
Gross calorific value of coal ash	4270 kcal/kg
Gross calorific value of fly ash	530 kcal/kg
Coal consumption (per1000 bricks)	58 kg
Coal powder used (per 1000 bricks)	65 kg
Fly ash (per1000 bricks)	241 kg
Average weight of fired bricks	2.3 kg
Specific energy consumption	1 26 ± 0 04 MJ/kg of fired brick

Energy balance

The important kiln parameters used for calculation of various energy balance components are presented in **table 4.1.8.** The energy balance for the VSBK-3 based on the measurement taken during the monitoring is presented in **table 4.1.9.**

Table 4.1.8 Important kiln parameters of VSBK-3

Parameters	
Average temprature of flue gas (measured at port-hole in the chimney)	232-250° C
Average temreture of unload bricks	80-120 °C
Estimated pure clay fraction in brick clay	32 %

Table 4.1.9 Energy balance of VSBK-3

Energy balance components	Percentage
Sinsible heat loss in flue gas	29.9
Potential heat loss due to 'CO' in flue gas	0.5
Heat for free moisture removal (drying of bricks)	15.7
Sensible heat loss on unloaded bricks	4.9
Heat for chemicals reactions	23.7
Structure and surface heat loss (by difference)	25 3
Total heat input-1 26MJ/kg of fired brick	100 00

VSBK-4

VSBK-4 is the kiln located at the Service Centre, Datia wherein the first monitoring was carried out During the second monitoring two shafts had been converted to single chimney system,and the monitoring of smaller shaft (1m X 1.5m)was carried out,having single chimney arrangement Some important kiln parameters are presented in**Table 4.1.10.**

Table 4.1.10 Imporatnt kiln parameters of VSBK-4

Parameter	Value
Average temrature of flue gas (at chimney arms)	55-150 °C
stimated pure clay fraction in brick clay	33 %

Specific energy consumption

Energy performance of the single chimney shaft was monitored Coal powder was added as internal fuel during clay presentation About 70 kg of coal powder was added as internal fuel,equvalent to 2 % by weightt In addition crushed coal(particle size less than 15 mm) is added on every layer of green bricks during loadingof bricks in the kiln.At the time of monitoring,abot 221 kg of coal was being added per batch(249 bricks) of bricks The gross calorofic value of coal and coal powder samples collected from the site as found to be 5100 kcal / kg .In energy terms the specific energy consumption was found to be 1 07 MJ / kg of fired bricks **(Table 4.1.11)** The higher energy consumption as compared to VSBK-1 monitoring may be attributed to the fact different soil (Varanasi soil) was used during the period of monitoring which required higher soaking tempretures for obtaining better qualities of the fired brick.

Table 4.1.11 Specific energy consumption of VSBK-4

Parameters	
Gross calorific value of coal	5100 kcal /kg
Gross calorific value of coal ash	5100 kcal /kg
Coal consumption (per 1000 bricks)	87 5 kg
Coal powder used (per 1000 bricks)	70 kg
Average weight of fired brick	3 1 kg
Specific energy consumption	1 07±0 04 MJ / kg of fired brick

A comparison of specific energy consumption of all four VSBK monitoring with other traditional kilns is presented in **figure 4.1.1**.The higher energy consumption level of VSBK-3 is due ti its non-stable condition during the period of monitoring Melting of bricks was observed which cleary indicated higher fuel input.

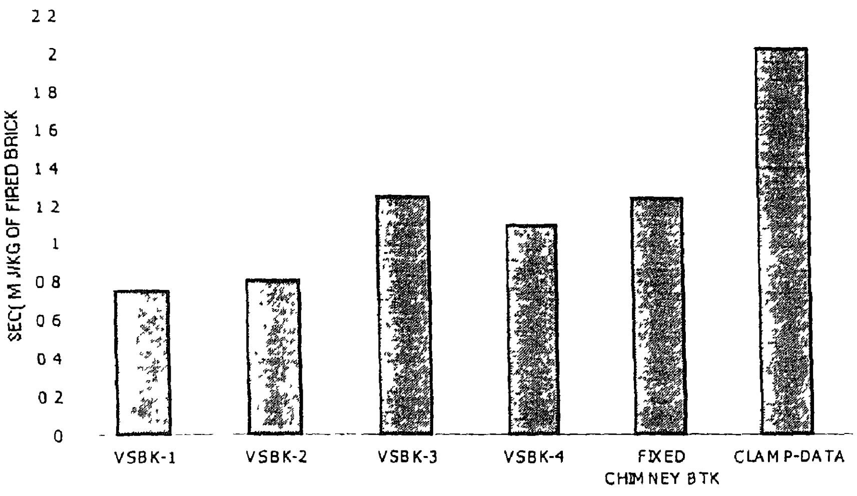

Figure 4.1.1 Comparison of specific energy consumption

Annex 4 2

Details of Stack emission Monitoring

S No	Date	Kiln	Shaft/ Chimney	Flue gas temp (° C)	Velocity (m/s)	SPM (mg/m^3)	SO_2 (mg/m^3)	NO_2 (mg/m^3)
1	0 3 05 01	VSBK 1	S1C1	76	2 1	106	19	41
2	03 05 01	VSBK 1	S1C1	76	2 1	127	19	45
3	03 05 01	VSBK 1	S1C2	75	2 2	93	15	37
4	03 05 01	VSBK 1	S1C2	75	2 2	140	22	38
5	04 05 01	VSBK 1	S2C1	81	2 0	202	25	29
6	04 05 01	VSBK 1	S2C1	81	2 0	176	14	50
7	04 05 01	VSBK 1	S2C2	87	2 1	157	17	36
8	04 05 01	VSBK 1	S2C2	90	2 0	158	13	46
9	05 05 01	VSBK 2	S1C1	168	3 0	307	27	64
10	05 05 01	VSBK 2	S1C1	174	3 0	236	30	70
11	05 05 01	VSBK 2	S1C2	169	2 8	258	21	57
12	05 05 01	VSBK 2	S1C2	178	2 8	232	36	87
13	06 05 01	VSBK 2	S2C1	190	3 0	236	44	91
14	06 05 01	VSBK 2	S2C1	188	3 0	249	40	88
15	06 05 01	VSBK 2	S2C2	194	3 0	272	42	85
16	06 05 01	VSBK 2	S2C2	190	2 9	267	42	75
17	10 12 01	VSBK 3	S1C1	120	1 5	74	39	55
18	10 12 01	VSBK 3	S1C1	120	1 5	84	45	72
19	11 12 01	VSBK 3	S1C1	134	1 5	84	34	63
20	11 12 01	VSBK 3	S1C2	118	1 2	81	118	65
21	11 12 01	VSBK 3	S1C2	123	1 2	57	65	81
22	11 12 01	VSBK 3	S1C2	130	1 2	81	73	69
23	17 01 02	VSBK 4	S1C1	78	1 15	224	48	72
24	17 01 02	VSBK 4	S1C1	82	1 15	218	44	78
25	17 01 02	VSBK 4	S1C1	82	1 12	234	62	70
26	17 01 02	VSBK 4	S1C1	80	1 12	170	58	74

S1C1 – Shaft 1 Chimney 1, S1C2 – Shaft 1 Chimney 2,

S2C1 – Shaft 2 Chimney 1, S2C2 – Shaft 2 Chimney 2

Annex 4 3

Ambient air quality monitoring

S no	Kiln	Location	SPM ($\mu g/m^3$)	RSPM ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)
1	VSBK 1	1A	218	NA	12	24
2	VSBK 1	1A	260	NA	10	20
3	VSBK 1	1A	346	NA	10	18
4	VSBK 1	1B	192	NA	18	32
5	VSBK 1	1B	NA	NA	NA	NA
6	VSBK 1	1B	243	NA	20	27
7	VSBK 1	1C	204	NA	11	19
8	VSBK 1	1C	212	NA	14	21
9	VSBK 1	1C	225	NA	15	25
10	VSBK 2	2A	328	NA	21	32
11	VSBK 2	2A	270	NA	NA	NA
12	VSBK 2	2A	224	NA	18	28
13	VSBK 2	2B	254	NA	18	27
14	VSBK 2	2B	189	NA	NA	25
15	VSBK 2	2B	215	NA	16	25
16	VSBK 2	2C	264	NA	10	29
17	VSBK 2	2C	NA	NA	NA	NA
18	VSBK 2	2C	352	NA	14	28
19	VSBK 3	3A	129	NA	6	31
20	VSBK 3	3A	147	NA	10	21
21	VSBK 3	3A	95	NA	11	13
22	VSBK 3	3B	135	NA	6	12
23	VSBK 3	3B	143	NA	7	27
24	VSBK 3	3B	98	NA	9	37
25	VSBK 3	3C	110	85	15	60
26	VSBK 3	3C	140	100	6	47
27	VSBK 3	3C	108	70	15	39
28	VSBK 4	4A	124	NA	8	27
29	VSBK 4	4A	99	NA	10	40
30	VSBK 4	4A	129	NA	10	38
31	VSBK 4	4B	116	75	12	32
32	VSBK 4	4B	126	54	13	35
33	VSBK 4	4B	116	NA	9	31
34	VSBK 4	4C	80	63	10	17
35	VSBK 4	4C	70	96	11	25
36	VSBK 4	4C	107	NA	9	13

NA – Not Available